Argonne National Laboratory

SURVEY OF POLARIZED ION SOURCES IN EUROPE

by

D. C. Hess and D. von Ehrenstein

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60440

SURVEY OF POLARIZED ION SOURCES IN EUROPE

by

D. C. Hess and D. von Ehrenstein

November, 1965

TABLE OF CONTENTS

INTRODUCTION

The additional information that can be obtained from nuclear experiments in which the orientation of the accelerated particles (electrons or nucleons) is known has encouraged development of sources of such oriented particles. This development has continued for a number of years and at this time there are some thirty "polarized ion sources," that is, sources for the orientation of nucleons or electrons, under discussion, under construction, or in operation throughout the world. (We will make no further mention of polarized electrons.) There have been some publications on these sources, and there was a conference in 1960. The report of this conference will be referred to as the "Basel Report."[1] recent survey by Dickson,[2] a book by Daniels[3] and the International Conference on Polarization Phenomena of Nucleons, Karlsruhe (September 6 — 10, 1965) and the forthcoming report therefrom (Birkhäuser Verlag, Basel), should also serve as general references. We will have frequent occasion to refer to the Abragam and Winter transitions.[4] Other references will be indicated as they become appropriate in the text. They will be noted by a footnote usually on the page on which they are first used.

As we too are building a polarized ion source (POLISO) for use with the Argonne Tandem, we wished to obtain more information. The publications (the Basel Report and some others) left many unanswered questions in our minds, the answers to which we felt

---

[1] Proceedings of the International Symposium on Polarization Phenomena of Nucleons, edited by P. Huber and K. P. Meyer (Birkhauser Verlag, Basel 1961), Helv. Phys. Acta. Suppl. VI.

[2] J. M. Dickson, Polarized Ion Sources and Acceleration of Polarized Beams, Progress in Nuclear Techniques and Instrumentation $\underline{1}$, 103 (1965) Farley (editor), North-Holland Publishing Company, Amsterdam. This report was published after we returned from our trip.

[3] J. M. Daniels, Oriented Nucleii, Polarized Targets and Beams, Academic Press, New York and London (1965).

[4] A. Abragam and J. M. Winter, Phys. Rev. Letters $\underline{1}$, 374 (1958); Compt. Rend. $\underline{255}$, 1099 (1962).

could best be acquired by personal contact with those who had built sources. Since there were many other groups which were at some stage prior to operation, we felt that a tour of those facilities in Europe which we knew to be concerned with this problem would be profitable. This report is a result of this trip.

It should be pointed out that this report is a quick revision of the notes we took on the trip. It suffers from possible errors in the notes which were a result of misunderstanding due to the fact that in some cases translation from one language to another took place almost simultaneously. The report is circulated for the general information of those concerned, and should be considered as a "private communication," rather than as a publication. None of the statements contained in it should be used without consulting the persons involved.

We both wish to express our appreciation for the hospitality offered us by the many groups we visited and for the kindness extended in answering our questions and discussing with us information which has not yet been published. We also thank them for their further help in correcting major errors in our interpretation of the discussions and for supplying us with figures as noted in the text.

November 22-23, 1964

1. University of Birmingham
   Professor P. B. Moon, Head of the Physics Department
   Professor W. E. Burcham, responsible for the Nuclear Physics
   Mr. W. B. Powell, Staff Fellow, responsible for the polarized
   source and the 40" cyclotron

They have a sector focused cyclotron using axial injection.
The general arrangement is shown (Fig. 1 copied from a special report
for visitors to the 40" cyclotron, 1964).[5-7] The cyclotron accelerates
deuterons to 12 MeV and He^3 to 32 MeV.
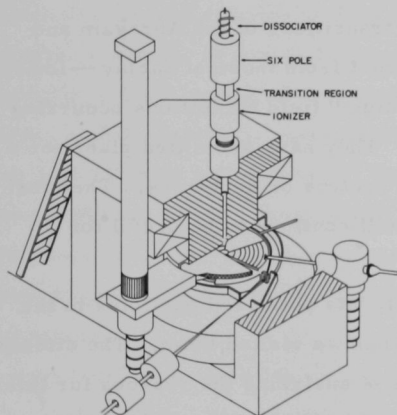
Fig. 1. Cutaway view of 40" radial ridged
cyclotron showing axial injection of polarized
beam from above (after Birmingham).
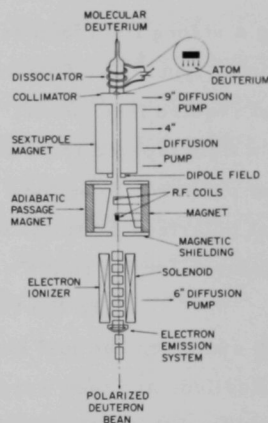
Fig. 2. Schematic drawing of
polarized deuteron source
(after Eaton).

The polarized deuteron source is similar to that at
Rutherford Laboratory, Harwell. A 6 pole, as at Rutherford, is used
and the multicapillary system also (Fig. 2). They found the multicapillaries

---

[5]"40" Radial Ridge Cyclotron," informal report, Department of Physics, University of
Birmingham, England.

[6]A. J. Cox, D. E. Kidd, W. B. Powell, B. L. Reece, and P. J. Waterton, Nucl. Instr.
Methods 18, 19, 25 (1962).

[7]W. B. Powell and B. L. Reece, Nucl. Instr. Methods 32, 325 (1965).

hard to make because of misalignment, twisting, and other fabricating difficulties (uniform heating is required). They now use units supplied by Rutherford (Dickson et al., ref. 13). The dissociator is similar to that at Rutherford, except here they use water cooling instead of air on the gas discharge. The water is inside the rf and they have no adverse dielectric losses. The water layer is several mm thick.

They decided to try transitions and Dr. T. W. Eaton (now at CERN) did the basic development. Some use will be made of his thesis.[8] B. L. Reece[7] worked on the axial injection system (1962).

They did not build a weak field ionizer. They are developing a strong field ionizer. They use rf transitions of the Abragam and Winter type.[4] The frequencies are different from those at Saclay—lower and require less power. They are "medium" field transitions occurring in a field tapered from about 13 to 5 G. They have submitted plans for a new cyclotron to be used with polarized protons or deuterons. They feel that polarized particles of $70-80$ MeV will continue to be useful for research for the next $8-10$ years.

The first attempt to accelerate polarized particles in the 40" cyclotron had just been completed when we visited them. The attempt had failed, and they were in the process of analyzing the reasons for this. It seemed that the ionizer was at fault (our conference supports this) and a new one is at present being designed. The polarizer has been very successful in producing neutrals away from the cyclotron. This has been tested with molybdenum oxide. The ionizer, tested separately with gas flow, not the atomic beam, indicated about 1% efficiency. There is a question as to where the ions come from. The assembly of polarizer and ionizer was put on the cyclotron. They got a good (but weak) beam. However, shutting off the 6 pole made no difference. To date (11/22/64) there

---

[8] T. W. Eaton, Production of a Beam of Polarized Deuterons by the Selection of Atomic Hyperfine States, thesis, University of Birmingham, 1964.

is no correlation between the accelerated beam and polarization.[*] It is probable that background gas is being ionized. They used a 2-pole Stern-Gerlach unit as an analyzer to measure the polarization and found that the tuning of the 6 pole is not too sharp.

The intensities (order of magnitude) are estimated to be 10^{19} particles/sec from the glass collimator (neutral), 2×10^{15} at the ionizer (neutral) or possibly less (roughly checked by experiment), one percent ionization efficiency (see later), and one percent transmission through the machine to an extracted beam. This latter one percent is a result of a loss of a factor of 4−5 from the top of the bottom of the magnet, a further factor of 2 during deflection, a factor of 4 for phase acceptance (duty cycle), a factor of $\frac{3}{2}$ from the first orbit to clear the center of the cyclotron, and a factor of $\frac{5}{4}$ in acceleration. The extraction loss is about a factor of 2. These values give hope of attaining a polarized beam of 10^{-8} amp on the target. They use a regenerative extractor which extracts a wide range of phases. They believe that the axial injection method is about twice as efficient as the usual internal ion source.

---

[*]July, 1965. Since our visit, a new stray field ionizer of different design has been built and successfully tested. With this 10^9 p.p.s. have been obtained through a $\frac{1}{4}$-in. aperture in the experimental area. This was reported briefly at the Eindhoven cyclotron in April. Polarization has been confirmed and a quantitative measurement will begin shortly.
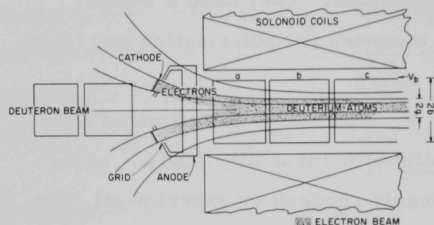
Fig. 3. Experimental arrangement for electron
ionization using longitudinal magnetic fields
(after Eaton). The cathode is to the left and
the electrons spiral about the converging lines
of field. The atomic beam comes in from the
right.

The ionizer is a
"solenoid" type, similar to the
one we have planned (Fig. 3).
The discussion of this type of
device trought up the possibility
of electron mirroring in analogy
with cyclotron vertical oscilla-
tions (and magnetic bottles).[9,10]

A discussion was
given by Sae Woong Oh who is
making calculations for a thesis.
The field in their ionizer is about
800 G. There is a stray field
above the cyclotron of about 200 G.

Using cylindrical polar coordinates, the Lagrangian for a
charged particle in a field is, ($\vec{A}$ is the magnetic vector potential)

$$L = \frac{1}{2} m(\dot{r}^2 + r^2\dot{\theta}^2 + \dot{z}^2) - e\phi + e(A_r \dot{r} + A_\theta r\dot{\theta} + A_z \dot{z}) \tag{1}$$

and since $\vec{B} = \nabla \times \vec{A}$ and for a solenoid, $\vec{A} = A(0, A_\theta, 0)$ where,

$$\vec{A} = \mu \int \frac{\vec{J}dV}{r} \quad (\vec{J} \text{ is the current density}) \tag{2}$$

we have, with z_1 and r_1 as unit vectors,

$$\vec{B} = -r_1 \frac{\partial A_\theta}{\partial Z} + z_1 \frac{\partial}{\partial r}(r A_\theta) \tag{3}$$

the first term represents B_r and the second term represents the B_z. Then

[9] O. Klemperer, Electron Optics, second edition (Cambridge University Press 1953) p. 224.

[10] Lyman Spitzer, Jr., Physics of Fully Ionized Gases (Interscience Tracts on Physics and Astronomy, New York 1956), No. 3.

$$\int_0^r r\, B_z(r_1 z)\, dr = r A_\theta \tag{4}$$

and by symmetry of the J and B,

$$\frac{\partial L}{\partial \dot\theta} = m\, r^2\, \dot\theta + e\, r\, A_\theta = \text{const.} \tag{5}$$

$$\frac{d}{dt}\, \frac{\partial L}{\partial \dot z} = m\ddot z = -e\, \frac{\partial}{\partial Z} - r\dot\theta\, e\, B_r \tag{6}$$

$$\frac{d}{dt}\, \frac{\partial L}{\partial \dot r} = m\ddot r = m\, r\, \dot\theta^2 - e\, \frac{\partial}{\partial r} + r\dot\theta\, e\, B_z \tag{7}$$

and from Eq. (5) for $\dot\theta_0 = 0$, we have

$$\dot\theta = \frac{e}{m r^2}\, [\, r_0 A_\theta(z_0 r_0) - r\, A_\theta(zr)\,]. \tag{8}$$

Also from Eq. (6) we get total reflection when $\dot z$ reverses,

$$r_0 A_\theta(z_0 r_0) = \int_0^{r_0} r\, B_z(rz_0)\, dr, \tag{9}$$

$$-r\, A_\theta(zr) = \int_0^r r\, B_z(rz)\, dr. \tag{10}$$

For a circularly symmetric field, such as produced by a solenoid, (Fig. 4) (10) > (9). If the particles start tangentially as 2, $\dot\theta_0 = 0$, when we consider the line from A as the (curvilinear) coordinate. This then reduces to the situation described by Spitzer,[10] pp. 9-11 (Fig. 5). The
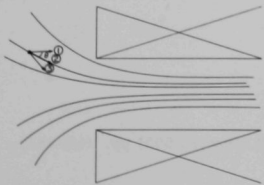

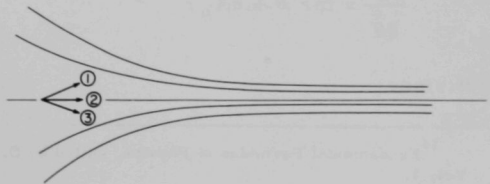Fig. 4. Different starting directions for charged particle in a converging magnetic field.

Fig. 5. Starting direction of Fig. 4 referred to "axis" of electron source.

critical θ_0 is obtained from $\sin^2\theta_0 = B_0/B_{max}$. If $\theta < \theta_0$, we have

transmission, if $\theta < \theta_0$, we have reflection. This can be pictured as in

Spitzer, as a turning due to the component B normal to the velocity. Note

that reflection is independent of mass, charge, and velocity.

Expansion of Sae Woong Oh derivation (cf. Menzel[11])

$L \equiv T - U$ and for conservative system,

$$\frac{d}{dt} \frac{\partial L}{\partial \dot{q}_k} - \frac{\partial L}{\partial q_k} = 0 \tag{11}$$

where the

$$p_k = \frac{\partial L}{\partial \dot{q}_k}$$

are the generalized momenta. If we have nonconservative forces

(magnetic, friction, etc.) the right side of Eq. (11) becomes F_k. Perhaps

we can find $M(q, \dot{q})$ so that

$$\frac{d}{dt} \frac{\partial M}{\partial \dot{q}_k} - \frac{\partial M}{\partial q_k} = F_k . \tag{12}$$

Define new Lagrangian $L = L - M$ and we again have 0 on the right. An

M for motion of electric charge e in EM field is,

$$M = \frac{e}{i} (\vec{A} \cdot \vec{V}), \tag{13}$$

where $\vec{A}$ is the magnetic potential and $\vec{V}$ is velocity of charge e. Sae uses

this to get his Lagrangian. Then Eq. (5) is derived

$$\frac{\partial L}{\partial \dot{\theta}} = mr^2\dot{\theta} + eA_\theta r \tag{14}$$

but since

---

[11]Fundamental Formulas of Physics, edited by D. H. Menzel (Dover S595) pp. 160-161, Vol. 1.

$$\frac{\partial L}{\partial \theta} = 0, \qquad \frac{d}{dt} \frac{\partial L}{\partial \dot\theta} = 0 \qquad \text{and} \qquad mr^2\dot\theta + eA_\theta r = \text{const} \qquad (15)$$

$$mr_0^2 \dot\theta_0 + eA_\theta r_0 = mr^2\dot\theta + eA_\theta r. \qquad (16)$$

and for $\dot\theta_0 = 0$,

$$\dot\theta = \frac{e}{mr^2} \left[r_0 A_\theta (z_0 r_0) - rA_\theta (z, r) \right] \qquad (17)$$

$$\frac{\partial L}{\partial Z} = -e \frac{\partial \phi}{\partial Z} + er\dot\theta \frac{\partial A_\theta}{\partial Z} = \frac{d}{dt} \frac{\partial L}{\partial \dot Z} = m\ddot Z \qquad (18)$$

since $\partial L / \partial \dot Z = m\dot Z$ and $A_Z = 0$. Also from $\vec B = \vec\nabla \times \vec A$ and $A = A(0, A_\theta, 0)$

$$B_r = - \frac{\partial A_\theta}{\partial Z} \qquad (19)$$

so

$$m\ddot Z = -e \left(\frac{\partial \phi}{\partial Z} + r \dot\theta B_r \right) \qquad (20)$$

$$\frac{\partial L}{\partial r} = mr\dot\theta^2 - e \frac{\partial \phi}{\partial r} + \underbrace{e A_\theta \dot\theta + e\dot\theta r \frac{\partial A_\theta}{\partial r}}_{e\dot\theta \frac{\partial}{\partial r}(rA_\theta)} = \frac{d}{dt} \frac{\partial L}{\partial \dot r} \qquad (21)$$

$$B_Z = \frac{1}{r} \frac{\partial}{\partial r} (rA_\theta) \qquad (22)$$

$$\frac{\partial L}{\partial \dot r} = m\dot r, \qquad \frac{d}{dt} \frac{\partial L}{\partial \dot r} = m\ddot r \qquad (23)$$

$$m\ddot r = mr\dot\theta^2 - e \frac{\partial \phi}{\partial r} + e\dot\theta r B_Z \qquad (24)$$

Eaton did the calculations on the ionizer and estimated the inner diameter of the electron cylinder in the absence of the stray field from the cyclotron to be about 1 cm. The polarized atoms are confined to a cylinder of about 1–2 cm diameter and it was thought that with diffusion there would be a useful angular region in which ionization could occur and that some of the electrons might even reach the center. (Questionable.) They now think that this was optimistic and that in any case the effect of the stray field from the cyclotron was underestimated. The ionizer is similar to our plans except they use a ring cathode. Since the radius of the cylinder is inversely proportional to H (ref. 25, Eq. 9.31), the "compression" depends on the ratio of the fields at the cathode and at the maximum. The maximum is about 800 G, and there is a stray field of about 200 G above the cyclotron so the diameter of the compressed beam will be affected. If the stray field and the solenoid field add, there will be a ratio of $(B_0 + 200)/800$ instead of the desired diameter ratio of $B_0/800$ (B_0 is the field in the region of the cathode). If the fields oppose, the ratio becomes $(B_0 - 200)/800$. This seems to indicate that the compression will be large if B_0 is only slightly larger than the stray field. However, the electron mirror effect may be serious. The above ratio calculations assume that the field inside the solenoid (800 G) is not appreciably affected by the stray field.

Powell suggested a uniform, bent field for the ionizer instead of the convergent magnetic field mentioned above. At Argonne, we had also considered a "tilted" field, that is one inclined to the axis. In both cases, we all (WBP, DvE, and DCH) concluded there was more danger of depolarization than with the symmetrical system and ion extraction might be more difficult.

They also extend the two opposite poles of the 6 pole to supply a dipole guide field. The need for this has not been established.

As listed below, both transitions (Abragam-Winter principle[4]) were effected in a weak external field H_0 with the rf component H_1 perpendicular to H_0. With the high frequency (329.4 MHz) the deuteron transitions $2 \to 5$ and $3 \to 6$ (for the labeling of the transitions see Fig. B on fold-out sheet at end of this report) are induced simultaneously producing an occupation of $\frac{2}{3}$ in the level $m_D = +1$ and the remaining $\frac{1}{3}$ in the level $m_D = 0$; the low frequency (7.5 MHz) effects (besides the unimportant exchange of the populations of levels 2 and 3) the transition $1 \to 4$ producing a $\frac{2}{3}$ occupation in the level $m_D = -1$ with the remaining $\frac{1}{3}$ again in the level $m_D = 0$ (ionization in strong magnetic field in all cases). The two frequencies are applied alternately to switch from + to - vector polarization. They believe that they attained an experimental transition rate of about 85% for both, corresponding to their theoretical expectation; but the results are somewhat uncertain, because they were obtained with molybdenum oxide pictures which were judged by the naked eye.

TABLE I. Summary of the parameters of the polarized
ion source.[8]

Dissociator

    Exciting frequency 15 MHz
    Ratio frequency power 200 – 300 W

Collimator

    1000 capillary tubes each 0.15 mm, O.D. and 1 mm long
        forming a disc 9 mm diameter and 1 mm thick

Sextupole Magnet

    Energizing current 150 amps at 3V
    Number of turns per pole, 6
    Magnet aperture, 0.8 cms
    Magnet length, 40 cms
    Field at pole tips, 6 kG
    Field gradient, 30 kG/cm at pole tips

TABLE I. (cont'd)

Adiabatic Passage Apparatus

    Field gradient, 3.5 G/in.
    Length of magnet, 8"
    Energizing current, 0.55 amps
    Number of turns per pole, 40

    a) High frequency transition
        Frequency, 329.4 MHz
        Field (H_0), 14.0 G
        Rf power, 2 W

    b) Low frequency transition
        Frequency, (7.5 ± 0.3) MHz
        Field (H_0), 7.5 G
        Rf power, 2 W

Ionizer

    Electron current, 250 mA
    Electron energy, 600 eV
    Volume of interaction with deuterium atoms, 16 ccs
    Diameter of atomic beam entering ionizer, 1.0 cms
    Measured ionization efficiency, 1%

Beam Characteristics

    Flux from dissociator, 10^{19} P/sec
    Flux from sextupole, 2×10^{15} P/sec
    Ionized current, 10^{10} deuterons/sec
    Polarization, $P_3 = \pm 0.6$

Pumping System

    1×9"
    4×4" oil diffusion pumps on sextupole vessel
    1×6" oil diffusion pump on ionizer vessel
    $1 \times$ I.S.C. 450 Edwards rotary backing pump

        The coils of the ionizer solenoid are wound with "mineral insulated cable." This is a Cu sheath (ca. 15 mil) over MgO (powder, ca. 5 mil) insulating the Cu conductor. It will handle several hundred

amps in the $\frac{1}{16}$ -in. conductor size (0.100-in. outside) in a cooled solid block. Voltage limit, "a few hundred volts," bending radius $\frac{1}{2}$ -in. (available from British Insulated Callendar's Cables, Ltd., Prescott, Lancashire, England).

There is the general question to what extent a radial ridge cyclotron might destroy the polarization. Some calculations have been made by H. G. Kim[12] under the guidance of Professor Burcham and indicate that there will be no depolarization in the case of the Birmingham cyclotron.

Dr. J. B. A. England
Physics Department
Birmingham University

The Nuffield cyclotron in Birmingham (60", 10 MeV proton) delivers 30 MeV He^3 with 150−200 keV resolution, 15 μA external beam (maximum, 30 μA). They are starting double scattering experiments to obtain polarization by the $C^{12}(He^3, a)C^{11}$ reaction; separation of the He^4 background by dE/dx and E counters; obtain experimentally 38% polarization at $27.5°$ in the lab. system, 10^6 particles/sec; counting rate after second scattering 1 event every 2 min; total background, 4−5 events/min (99% of this is suppressed by the counter telescopes).

Dr. S. Roman
Birmingham University

Dr. Roman has produced polarized protons with 40 MeV a beam from Nuffield cyclotron on hydrogen target (Rosen technique). With these protons he made a survey of polarization measurements over the medium weight nuclei. Recently he put He^3 in deuterium gas and produced polarized deuterons (preliminary).

---

[12]H. G. Kim and W. E. Burcham, Nucl. Instr. Methods 27, 211 (1964).

Dr. Peter Rolph
Birmingham University

  Dr. Rolph made scattering and polarization experiments on
medium weight nuclei with the 10 MeV protons of the Nuffield cyclotron to
eliminate ambiguities in connection with the optical model.

Rutherford   November 25-26, 1964

2. Rutherford High Energy Laboratory
  Chilton, Didcot, Berkshire
  Mr. John M. Dickson
  Mr. Donald A. G. Broad
  Mr. Antony P. Banford
  Mr. Richard C. Carter

  A polarized source has been used on the 50 MeV proton
linear accelerator for some time.[1,17] They would only get about 25 MeV
particles if they used deuterons. They have a 6 pole about 9-in.
diameter outside, 8 mm diameter inside. At the pole tips the flux is
about 6000 G and B' about 30 000 G/cm. The pole shape is the usual 30°
sector. They want to make a new magnet with a larger aperture and
higher B, in order to obtain higher intensity. They have improved the
ionizer described in the Basel report (Mark I)[1] by stiffening the electrode
plates to decrease the warping due to heating. This ionizer delivered
0.12 μA of polarized protons on the test bench (but the beam had a larger
solid angle than could be accepted by the Linac) and about 2 μA of back-
ground which included about 0.02 μA of unpolarized protons.[13]
  For more than a year they have used the Mark II ionizer[14]
efficiency of 2 or 3 times that of Mark I. Mark II uses a "grid" of annular

---

[13] PLA Progress Report, 1963, NIRL/R/60.

[14] PLA Progress Report for 1964, NIRL/R/81.

Fig. 6. Arrangement of the Mark II ion source.
The six filaments are at 3700 V, the fins and
anodes are at 4000 V. There are 45 anode
discs of 0.15 mm thick tantalum, spaced 1
mm apart. The extractor is at 0 V. The
water-cooled space is at filament potential.
The grid nearest the extractor is at 0 V and
the rear double grid is at 4000 V (after
Dickson, ref. 13).
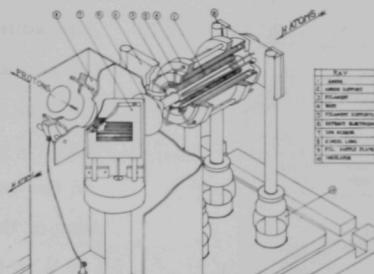
rings or plates (Fig. 6). Electrons are introduced radially from six
filaments on the outside. There is about 3 amp of electron current at
300 V. There is a funnel type extractor at 2 to 4 kV. Extraction is axial.
They think this is twice as good as the previous type. The efficiency is
probably about 10^{-3} (upper limit). The total length is about 4 cm, but the
useful length of the anode is only about 2.5 cm. They have not tested for
optimal length. The center hole is about 9 mm diameter. The outer case
(not the vacuum chamber) is water cooled and is at filament potential. The
extractor is at "ground" and the cathode assembly is positive. The anode
structure runs hot and the tantalum acts as a very effective getter. As a
result, they have a low background and obtain 36% polarization, in MK I
30% was obtained. The W filaments (0.024") are stretched through holes
in Mo blocks (Fig. 7). The spring tension is
supplied by nimonic, which is similar to inconel-x
(the springs, protected by the cooled shell, operate
1 mm W hooks). The filament-anode spacing is
about 1 mm. The six filaments are connected in
parallel. They are supplied by a current trans-
former with a core of slotted 2 mil Hipersil, and a
single turn secondary passing through a silica tube.

Fig. 7. Upper figure
shows how filaments
are threaded through
mounting block. Lower
figure shows assembly
with tensioning support.

One can monitor the filament current in the primary as the unit acts as a
current transformer, primary reactive current is annulled by capacitor.
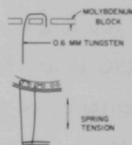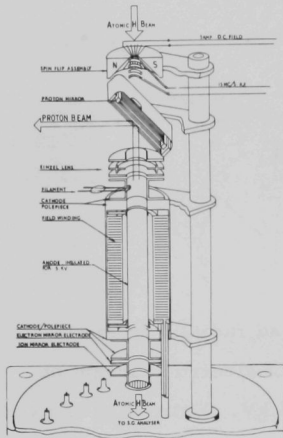The operating frequency is 2 kHz. The filaments draw 200 A at 5 V thus

Fig. 8. General layout of the
Mark III ionizer as originally
conceived (after Dickson,
ref. 14).

contributing an additional kilowatt of heat to the source region. The mirror grids are "wrapped" W wires on a "comb-slot" combination as shown for Mark III, Fig. 8. They have a protective resistor of several megohms in the mirror circuit. There is about 1 μA out of the extractor. There is a loss of about 10 x in the mirror system. This is due to excess beam divergence. The excess divergence is thought to be caused by diverging lens action of the space charge and also oscillation of the ions. The angle of divergence is approximately a $45°$ cone. There was no space to put an einzel lens between the extractor and the mirror so they had to be satisfied with one after the mirror. The "fins" opposite the extractor are at anode potential to inhibit ion extraction in the unwanted direction. Since this is a weak field ionizer, they use a Helmholtz triplet to allow selection of any direction of polarization.

They have approximately 2×10^8 particles/sec after acceleration (50 MeV p). The Linac has a duty cycle of 1% and there is a loss of a factor of about 40 in tank 1, including the phase acceptance. Thus, $40 \times 100 \times 2 \times 10^8 \approx 10^{12}$ particles/sec d.c. from the source. The POLISO is at +500 kV. There is a possible loss of a factor of 2 between the ionizer and the beginning of the 500 kV accelerating column. They hope for 1 μA d.c. with the new (Mark III) strong field ionizer.

The Mark III source is a solenoid strong field ionizer somewhat as described for Birmingham with the difference that the electrons are supplied mostly by "reuse" of those in the region by "Penning" action (Fig. 8). There is a filament to supply a small "tickler" current (a few hundred μA) which, together with the electrons from ionization, will produce a large effective current (about 4 A estimated). There are iron

poles at the ends which have holes to admit the beam. The termination thus gives a bit of stray field. One might even like more to guide the neutrals until they are ionized. The derivation of this ionizer from the Penning gauge is shown in Fig. 9.

Several effects were noticed. As the input electron current was increased, there was a saturation of ion current. They said that the theoretical maximum circulating current was 4 A at 5 kV. Extraction is at the end. In summary, with Mark I, they had 0.1 μA protons from the beam, 2.0 μA rubbish (of which about 0.02 μA was protons) with Mark III, they hope for 1 μA protons from the atomic beam.

NOTE: December 20, 1964 Pers. Comm. from Dickson in Erlangen. With Mark I, they got 10^8 protons per sec through the machine. The first test on the accelerator with Mark III gave 10^7, not polarized. With the dissociator rf off, there is less than 10% change in the beam so the ionizer was not seeing the atomic beam. They think some of the trouble was that there was contamination of the mirror by oil, since there is about $\frac{1}{4}$ mA leakage and emission. The mirror voltage is about 1000 V too low.
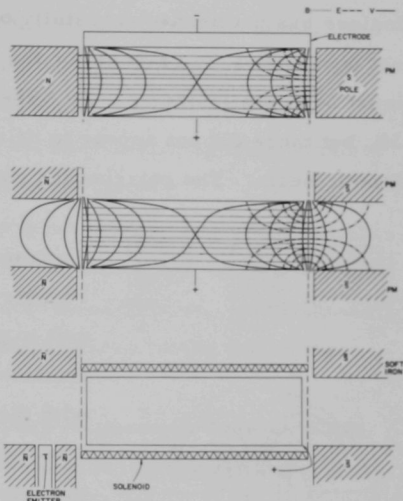

Fig. 9. Development of the Penning discharge into the ionizer. In the top figure, the field is supplied by a PM to flat poles. In the second figure, the poles have been drilled out as shown, and also supply the negative potential. The field lines are slightly changed as shown but inside the cylinder, the effect is the same. In the third figure, the magnetic field is supplied by the solenoid and a small filament has been added to supply the "starting" electrons. The fields would be similar. The starting electrons would follow the field lines into the ionization volume which is mostly inside the cylinder. Refs. 16−20 give a general basis for this type of ion source.

Further note, December 30, 1964 (letter, Dickson). "The modified polarized source here with adiabatic passage and strong field ionizer has not been successfully operated yet on the accelerator. We do not understand the reasons for the failure, but I feel sure that the fault must be in the ionizer . . ." "The beam intensity was low by a factor of 10, but there did not appear to be a proton beam associated with the atomic beam. The polarization obtained was nearly zero."
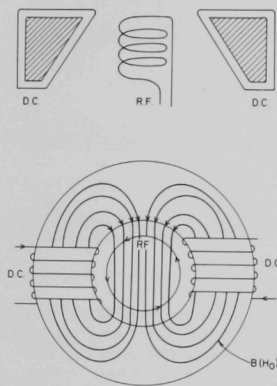

The magnet they plan to use in the transition region is quite similar to a TV sweep coil. It can be considered as a "shimmed" unit to give a uniform field over a larger fraction of the pole face than would be expected with the usual parallel pole faces (Fig. 10). The coils are of heavy wire; two of six turns each operated in series at 5A. The rf is about 15 Mc and the d.c. field is 15-5 G over the region of the rf coil. Another advantage of this design is that there is some shielding against stray fields. They also use two poles of the 6 pole extended to provide a guide field.[*] They use

Fig. 10. (a)Cross section of transition unit. (b) Plan view of transition unit.

a little transistor oscillator as only about 5% frequency stability is needed. Although it is possible to get "satisfactory" results with a 10:1 variation in output, they feel it is simpler to amplitude stabilize the output. A small diode (in the vacuum near the coil) is used to detect the coil peak rf (not for stabilization). The circuit is a Hartley. They expect to end up with a small fixed tune unit, with about 100 mW.

Their water safety circuits use conductivity switches. The water flows through a PTFE nozzle, onto an electrode at 200 V above "ground." There is a series resistor, and the electrode is stainless steel. A current of about 1 μA controls relays through a transistor amplifier.

---

[*] Cf. comment on Page 10.

The refrigerator for the baffles is at ground (actual, not reference) and the freon is piped up to the 500 kV through Teflon tubing which is resin bonded paper (SRBP) wrapped to hold the pressure.

The mechanical pump is mounted on a long time constant suspension to reduce vibrations coupled to the mount.

Compressed air controls (push buttons and switches) are used. They give a response time of < 1 sec over 100 ft at 15 psi. The compressed air operated switch, specially manufactured, costs about 30s ($4.20). A Dowty seal is used, with polythene tubing (nylon for higher temperatures).

For the pumping fluids, they recommend Diffelen Ultra, Leybold catalog No. 17671. For the atomic beam test apparatus, they use a small (Edwards 2") diffusion pump with the heater power raised from 250 W to 350 W and a special oil, pentachlor diphenyl from Monsanto or (the same as) arachlor, Edwards No. 1254. They use Edwards No. 1248 for the mechanical pumps. They also use arachlor on the high throughput booster stage in the POLISO. The booster runs over a range from 1μ to 0.6 Torr.

On the test setup, the 2-in. pump is used as a booster for a 9-in. pump on the dissociator and three 6-in. pumps on the magnet and ionizer chambers. A water-cooled baffle is used with the booster and arcton (freon) cooling is used on the other baffles. On the top of the 9-in. unit, the pressure is 6×10^{-5} with a flow of 0.25 cc/sec H_2. Liquid nitrogen is needed before a good vacuum is obtained in the ionizer. The test unit is made up of aluminum alloy (machined from a solid block of Dural, no welds) with Viton A O ring gaskets of 0.139 secondary diameter. They feel the use of the booster may prevent polymerization of the pump oil. No trouble experienced after three to four months operation.

Construction of the multicapillaries is described in the 1963 Progress Report.[13] The pyrex is cleaned, not coated. The cleaning is done with ammonium hydrogen difluoride (NH_4FHF) (97% purity) 40 g, concentrated nitric acid, 20 cc and H_2O 2000 cc. The items are immersed 2 to 5 min. Longer time etches the glass. The capillaries are good at the start and get a little better with age. Times of over 2000 hours have been obtained. Best length of collimator about 1 mm.
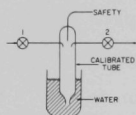
A water rise type of H_2 flow meter is used. The time it takes the liquid to rise in a calibrated tube gives the rate (Fig. 11). There are separate

Fig. 11. Flow meter. With the water level stationary, valve No. 1 is closed and the rate of rise of water in the calibrated tube is noted.

needle valves. The third outlet is for safety. Valve No. 1 is closed and the time is measured. The rate has been originally set by adjustment of valve No. 2.

There are approximately 90 magnetic 4 poles in tanks 2 and 3 of the Linac and beyond. They estimate the maximum total tilt (of polarization) would be $10°$; the average is less and is equally distributed about zero. With the strong field ionizer and the mirror, one will have vertical polarization through the Linac. It can be precessed to horizontal by use of a solenoid surrounding the proton beam between mirror and accelerating column.

There is a polarization monitor which depends on scattering, and an energy monitor using wedge absorbers. These are also described in the 1963 Progress Report.[13] The scintillation produced by the beam in plastic scintillator is observed by TV for setting up beam lines. Needs about 1 μA peak. The polarized beam gives (at present) about 3 nA peak which is below the threshold of visibility on the scintillator.

The dissociator. Pyrex is good, quartz is probably better. Coating with Silane has more drawbacks than advantages, it cakes and

blocks collimator. The discharge is air cooled but water cooling should be advantageous. Need $200-500$ W. Can detect $\frac{1}{2}^{\circ}$ tilt of the collimator. Having Teflon in the discharge is bad, appears to decompose. The H_2 should ideally be handled in Teflon, polyethylene or noncorrodible metal. Broad thinks the use of oil bubblers and any large volume apparatus in H_2 line is bad and they don't use them. They use high-purity tank hydrogen.

Might consider the possibility of using AgCl as cement instead of the spring clip or seal suggested in Fig. 12.

Plate all Fe surfaces, otherwise rust will form due to H_2O vapor. Use Ni or Cr, "satin chrome." (Other experimenters say plating is not necessary, cf. p. 26, Saclay.)
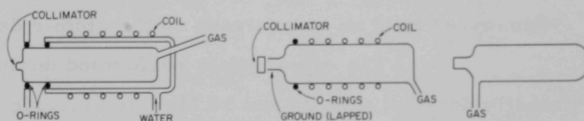

Fig. 12. Three suggested variations of the dissociator unit. (a) shows a water jacket of lucite, tempered polystyrene, tempered polyethylene, or Teflon. It is sealed with O rings. (b) shows a suggested way of making the collimators quickly interchangeable. The collimator unit is fastened with spring clips of a "finger stock" type. This unit might be cemented instead. (c) is intended to indicate gas introduction near the exit instead of at the opposite end as usual. Various combinations of these features are of course also possible.

Broad thinks ion pumps used with oil pumps are bad (so does Clausnitzer), but Eindhoven people don't think so nor do those at Basle and Washington. These groups have differential pumping.

They are fussy about the type of stainless steel they use. Broad says that repeated heating and cooling from room temperature to 90°K tends to render porous brazed joints between Cu and the easy welding type of stainless steel (which contains more carbon than other types? Brazing to inconel appears safe).

Normally they can get about 70% dissociation in plain glass, and it becomes higher after some days. There seems to be some sort of conditioning of the system. The proton current changes but there is no color change in the discharge, neither visible nor detectable with a

spectroscope (but cf. Milan),[15] the tank coil of the rf oscillator is to
be around the discharge tube. No rf transmission line would be needed,
and rf can be enclosed by single casing. He is thinking of using one of
the small disk seal tubes right in the dissociator system. He is also
thinking along those lines for the transition unit and its transistor (cf.
above). With the dissociator, one could have also a fixed tune arrange-
ment with no variable C. On the atomic beam test unit, they will use a
"two-wire" field as an analyzer on the atomic beam.

The experiments performed during the last years were
mostly done between 20 and 50 MeV and include p-p (P, A, R, and D
parameters), p-d, p-He, and p-N.

Note added in proof (12 July 1965). Mark III has had its
end electrode configuration modified as a result of laboratory tests, and
now has the electrons injected axially from the bottom. Stern-Gerlach
analysis of the atom beam has confirmed the correct operation of the
spin flip (measured efficiency $\lessgtr$ 90%).

On the proton linac, a 50 MeV beam of 2×10^8 protons/sec
at 50% polarization has been obtained. This low polarization is mainly
due to dilution by background protons. Mark III does not have the
gettering action of Mark II, and to reduce hydrogenous background it will
be necessary to use liquid nitrogen baffles on the accelerating column of
the 500 kV injector.

---

[15] Cf. Milan, Useful tables are available in G. W. Series, Spectra of Atomic Hydrogen, (Oxford University Press).

[16] R. L. Jepsen, J. Appl. Phys. 32, 2619 (1961).

[17] M. K. Craddock, The Nuclear Interaction of High Energy Particles, PhD thesis, 1964, Faculty of Physical Sciences, Oxford University.

[18] J. B. Warren, Progress in Fast Nuclear Physics, Rice Conference of 1963 (University of Chicago Press) p. 395.

[19] J. C. Helmer and R. L. Jepson, Proceedings Inst. Radio Eng. 49, 1920 (1961).

[20] R. Weiss, Rev. Sci. Instr. 32, 397 (1961). The Kurchatov Institute, Moscow, is supposed to have an ionizer (for their POLISO) that gives 0.1 mA.

3. Centre d'Etudes Nucleaires de Saclay

There are three polarized ion sources at the Centre
d'Etudes Nucleaires de Saclay (C.E.N.) Two of them are at Service
SPNME: Professor J. Thirion, Dr. R. Beurtey. A cyclotron delivering
22 MeV deuterons with a polarized source has been in operation for
several years (40% experimental polarization, 3×10^{-11} A)[21] and a
variable energy cyclotron (Philips) for 30 MeV protons to which a newly
constructed polarized proton source has been connected. Preliminary
successful tests of the polarization have been performed during the winter
months of 1965 (later information).

The third polarized source is being constructed at the
Service SPNBE: Dr. B. J. Delaunay for the 12 MeV EN-Tandem Van de
Graaff and should be tested this year (see later).

All three sources operate or will operate with adiabatic
passage transitions[4] which were proposed at Saclay by A. Abragam and
J. M. Winter and first tested there.

Visit at SPNME (Thirion)

Neither of their cyclotrons has an axial hole. At present
they drift the neutral polarized beam into the center of the accelerator
where it is ionized. They may use an external ionizer and introduce the
ions into the center with a system of rods to form an electrostatic com-
pensator for the magnetic forces. Calculations look very promising, but
they would still prefer an axial hole if they had a choice.

For the new Philips variable energy cyclotron. The
dissociator is as at CERN. They are built in rf "chokes" in the tubing.

[21] R. Beurtey, R. Chaminade, A. Falcoz, R. Maillard, T. Mikumo, A. Papineau, L.
Schecter, and J. Thirion, Journal de Physique 24, 1038 (1963) and earlier publications listed
there.
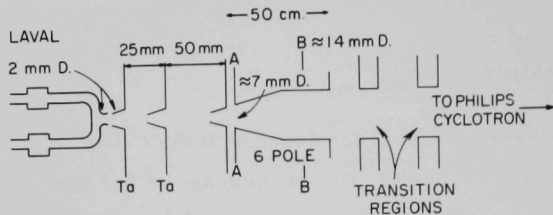
Fig. 13. General outline of POLISOS used at SPNME. The dissociator is electrostatically coupled to the dissociator which is made of pyrex, cleaned with H_2F_2. The discharge operates at about 2 Torr. The region between the Laval nozzle and the first (peeler) plate is pumped by a 1500 $m^3/$hr Roots pump. The second region is pumped by a 2000 L/sec. Hg diffusion pump with a liquid nitrogen trap. The pressure is about 7×10^{-5} Torr. The third volume (50 mm preceding the 6 pole) is maintained at $1-2 \times 10^{-5}$ Torr by a 3000 L/sec oil diffusion pump. The first transition region is a low frequency, low field system. The field is about 10 G and shielding from the stray field of the 6 pole is necessary. The second transition takes place in a high field supplied by the fringing field from the cyclotron.

The general outline is as in Fig. 13.

With their pumping arrangement they found that one pump was as good as two in parallel. They checked by valving off.

The laval nozzle is supposed to give supersonic flow. In order to obtain this, it is necessary that the mean free path be longer than the opening (diameter). They also feel that wet hydrogen prevents recombination on the walls and is better. They use a water bubbler.

The beam with the detector (vacuum gauge, with a 7 mm diameter, 15 cm long ram tube) at the exit of the 6 pole gives a pressure corresponding to $2-3 \times 10^{17}$ particles/sec over an area of about 5 mm diameter. At 1.5 m from the 6 pole, there are about 2×10^{16} and the beam is about 1 cm in diameter. This corresponds to a pressure of $\frac{1}{2} - 1 \times 10^{-6}$ Torr. The ionizer in the cyclotron is designed to accept the neutral beam at a position not in the plane of the ion orbits, ionize it and inject it into the orbital plane by reflection in an ion mirror (Fig. 14). All the parts are at liquid N_2 temperature. The residual hydrogen is about $20-25\%$ of the beam. The ionizer uses the Penning principle. Since it is in the center of the sector focused cyclotron there is sufficient field. The source is completely enclosed (and cooled as mentioned) to decrease the effects of residual vacuum and the background is adequately

reduced even for

protons. The

source is a com-

pletely separate

unit. The effic-

iency was about

10^{-6} on the test

bench. They get

$\frac{1}{2}$ nA internal beam

Fig. 14. Simplified schematic diagram of the ionizer used on the Phillips cyclotron at SPNME. The lower shading represents the pole face. Electrons are reflected from grounded plate and the grounded ring to produce a "Penning" type source. The ions are extracted upward at -4 to -5 kV and are reflected by the mirror into the median plane of the cyclotron.
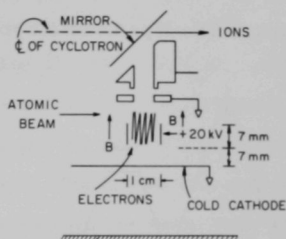
and about 0.3 nA on the external probe. They hope to get $10^8 - 10^9$
particles/sec onto the target. The loss is due to phase acceptance, etc.
The effects on the polarization of the ionizer and of acceleration of the
particles in a sector focused magnet had not yet been determined at the
time of our visit.

For the old

cyclotron a broad beam (high in

terms of extension along the

direction of the magnetic field)

is useable (Fig. 15). They get

about 10^8 particles/sec on the

target. They feel it might be

better if they injected electrons.

Thirion thinks they should get

$10^8 - 10^9$ as a minimum.

Fig. 15. (a) Top view of ionizer for the old cyclotron. The small circles are cathodes with the configuration shown in 15(b). Electrons follow spiral paths into the anode because of the magnetic field. Ions spiral out and enter the cyclotron. There is no emitted "beam." (b) Horizontal view showing the shape of the cathodes and anode.
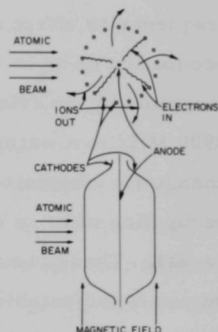
Details on the 6 pole. It is 50 cm overall. The poles are 7 mm apart at the entrance, expand linearly for 250 mm to 14 mm and then stay 14 mm for the remainder of the length. The yoke is 6 cm thick. The tips have a cross section somewhat as indicated by Fig. 16.
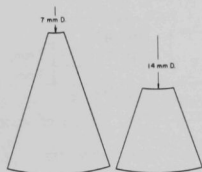
Fig. 16. Approximate cross section of pole tips for the six-pole lens.

They are of mild steel, with only the requirement that $0.06\% < C < 0.15\%$. They are not plated. The coils are cast in araldite and encased in stainless steel. They are of 18 turns each and carry up to 200 A, twice the maximum needed for 30 cm focal length. For the usual operation with 150 cm focal length they need only 50 A. The solid angle is a function of the speed in the 6 pole. The best theoretical form is approximated by the pole shape they use.

In the proton source described here they need only two transitions[4] to switch the sign of the polarization. One, a "weak-field passage" ($\pm m \rightarrow \mp m$) using about 10 G and a few watts of the proper frequency to effect the transition $1 \rightarrow 3$ (Fig. A) which yields a 100% occupation of $m_p = -\frac{1}{2}$ and the other, a strong field transition at 884 G (supplied by the fringing field of the cyclotron) with 400 W of power at 2900 MHz in a water-cooled cavity (without water cooling the heat would change its dimensions) to effect the transition $2 \rightarrow 4$ which yields a 100% occupation of $m_p = +\frac{1}{2}$ (ionization in a strong field is assumed in both cases). These two transitions can be alternately turned on and off in intervals (adjustable from $\frac{1}{10}$ sec to several seconds) given by an electric clock. A lock-in detector is used to obtain maximum effect of the changes from negative to positive polarization.

The proton polarization will be tested with a carbon target and a single counter, flipping the spin. Later they intend to measure 16 angles at the same time. The polarization will be monitored after the beam passes through the experimental target.

There was a short discussion of a polarized proton target to be used with a polarized proton beam. A thin target is needed as the experiments are done by transmission. They have a 0.1 mm thick crystal in a 19 kG field. The material is $La_2Mg_2(NO_3)_{12} \cdot 24H_2O$. About 50% of the hydrogen nuclei of this target can be polarized. Polarization must be known to about 1%. The energy is changed by use of an absorber.

For the strong field transition unit, the cavity had a Q of about 1500 so the frequency must be stable to maintain the amplitude in the cavity. For protons, the field is 884 G and the frequency about 2900 MHz. For deuterons, the field is 980 G and the frequency also about 2900 MHz. As many as three transition regions may be used simultaneously for deuterons (only one of two regions is used at a time with protons as already noted). The apparatus is arranged with a weak field region, a strong field and then a weak one.[21] The desired combination of transitions is obtained by switching of the low-frequency amplifiers (they use 7.4 MHz in one and 7.6 MHz in the other to avoid beats: we are not sure why they don't use a common oscillator since the amplifiers are keyed)with the electric clock mentioned before and gated scalers.

The high-frequency cavity is water cooled as the power dissipated may be as much as 400 W and the dimensions in the cavity are critical because of the high Q involved. The beam is inside a quartz tube. One would like to keep the external field (H_0) as small as possible as the decoupling of the electron and proton increases with field and more power is required. It is also desirable to keep the power low for the low field transition. They ran efficiency vs power curves and found in most cases a few watts were sufficient (see below).

The normal cyclotron arc source with N_2 as the principle gas gave high efficiency but depolarized the beam.

In Saclay they have considered plans to ionize the polarized beam, to accelerate it, shape it, neutralize it (in an adder gas), drift the particles into the center of the cyclotron where they are to be ionized by a gas stripper. But they don't intend to use this method because the proposal to introduce the externally produced ions into the center of the cyclotron compensating the magnetic deflection with an electric field (see above) seems to be better.

Maillard on transitions and their efficiency: about 20 W is normally used for the weak field transitions near 7.5 MHz (up to 70 W is available with their arrangement). For power measurement, they compare the bulb brightness with a standard bulb which is controlled by a rheostat across 110 V (Fig. 17). The line shown is about 2 m long so is only about $\lambda/20$, thus there are no problems with standing waves. The curve

Fig. 17. Coupling and power measurement circuits for low field transitions.

in Fig. 18 is similar for high $(\Delta F = 1)$ or low $(\Delta F = 0)$ frequencies. As shown, the curve starts to go down at about 1.5 W with the arrangement of Fig. 17. They used a keyed amplifier with a lock-in detector system to enhance the effect of the change in polarization. A square wave of period 0.1 to 10 sec is used. Different transitions allow switching between
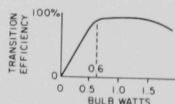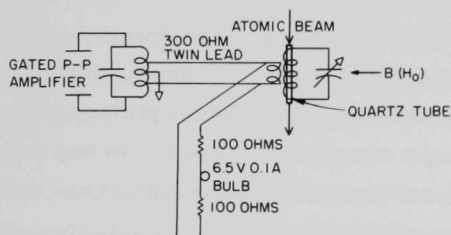
Fig. 18. Variation of transition efficiency with applied power for low field transitions. Note the abscissa is not the total power used in the transition field.

different modes of
polarization. The
timing is by the line
frequency scaled down
(see Fig. 19).

Fre-
quency stabilization
of the low frequency

Fig. 19. Arrangement for mode switching by radio frequency keying. The strong field transition is always on. For Mode 1 (cf. Fig. 21) both weak fields are off. For Mode 2, the first is on and the second is off. For Mode 3, both are on and for Mode 4, only the second is on.

oscillators is not important, 1% stability is enough. However, it seems
to be important to have the proper wave form in the quartz tube. There-
fore, one needs careful tuning. Cleanliness of this tube is equally
necessary. They found that Hg inside the quartz, caused by an uncooled
baffle, shifted the frequency and the transition became weak. They watch
the brightness of the light bulb continuously to check the matching.

The general method they use to produce the different modes
of deuteron polarization has already been described.[21] It uses none, one,
or both of two weak-field transitions   (8 G with a gradient of $\pm$ 2 G,
7.4 MHz and 7.6 MHz; the different frequencies were chosen to avoid
beats — see comment above) and a strong field transition (about 1000 G with
a gradient, 2900 MHz).

It was difficult to find a 3000 MHz oscillator which could
give a continuous power of 400 W. Since the Q value is around 3000[*] the
frequency stability has to be 10^{-4}. A magnetron was not stable enough,
possibly because of heating. They finally found the Carcinotron CM 7080
(made by CSF — Compagnie Sans Fil) the frequency of which can be varied
between 2500 and 3600 MHz by changing a single voltage, but its supply

---

[*]The Q was about 1500 and was raised to about 3000 by better con-
struction. For example, the choke should be good.

needs to be well stabilized. The requirements are: "tension de Ligne" 4 kV, 400 mA, 2×10^{-5}; filament supply 6.3 V, 2.8 A, 1%; anode variable from 700 to 1250 V, 1 mA 2×10^{-5}; "sole" 700 V, 70 mA 2×10^{-5}; "tension de Ligne" is actually grounded and all other voltages are at elevated potential corresponding to the potentials mentioned. The water for cooling the carcinotron is taken from the general supply. After a one hr warmup the frequency has the required stability for many hours. The cooling water for the cavity is in cascade with that from the carinotron and one expects some degree of cancellation of detuning effects due to changes in the water temperature. Figure 20 shows the arrangement.
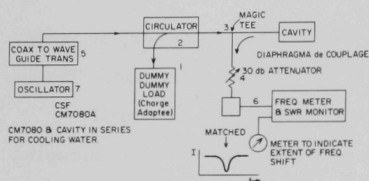
Fig. 20. Circuit elements for high field transition. Figures correspond to those in Table II.

Discussion with Dr. R. Beurtey. Beurtey drew our attention to a diagram (Fig. 21) describing all possible combinations of vector and tensor polarization of deuterons. The circled points 1, 2, 3, and 4 correspond to the different modes of polarization they attain with the method described in the above-mentioned publication.[21] Adding the results of Mode 1
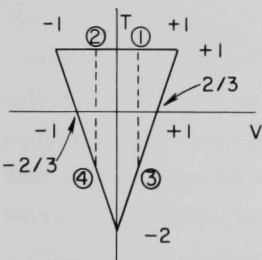
Fig. 21. Representation of combinations of vector and tensor polarization. The ordinate is tensor polarization and the abcissa is vector polarization. The modes indicate various mixtures that are obtained with the transition combinations of Fig. 19.

and Mode 2 should yield the effect of pure positive tensor polarization and eliminate the effects of vector polarization, adding Mode 3 and 4 gives pure negative tensor polarization without vector polarization. Correspondingly, a combination of 1 and 3 compared to 2 and 4 gives the effect of a change

TABLE II. High frequency parts listed by Maillard
(Saclay).

	Numbers on Fig. 20
1 Charge Adaptée forte puissance Type RF104 COTELEC, 11 rue St. Florentin Paris 8e, Tel.: OPEra 30-58	1
1 Circulateur à Ferrite Type R2905 LTT, 89 rue de la Faisanderie, Paris 16e Tel.: TROcadero 45-50	2
1 Coupleur directif Type CD101 30 db COTELEC	3
1 Attenuateur variable Type 1406 AMEP, 13 square Henri Platé, Paris 16e Tel.: AUT 64-97	
1 Couplage Guide-Coaxial Type 109A AMEP	5
1 Ondomètre Type 1403 with adapteur à piston Type 113 AMEP	6
1 Carcinotron CM 7080A CSF, 55 rue Greffullre Levallois-Perret (Seine) Tel.: PER 34-00	7

from plus to minus vector polarization cancelling effects of tensor
polarization. (Theoretical maximum of obtainable polarizations with
their arrangement: vector polarization $P_3 = \pm \frac{2}{3}$, tensor polarization
$P_{33} = \pm 1$).

One should make a distinction between two types of
transitions—low frequency transitions corresponding to $\Delta F = 0$ and
high frequency transitions corresponding to $\Delta F = 1$. Both types can be

performed as adiabatic passages with an almost 100% transition rate
as proposed by Abragam and Winter.[4]

The $\Delta F = 0$ transitions in a weak field are normally
effected by exposing the atoms to a frequency corresponding to the energy
difference (for deuterons as an example) between level 1 and 2 =
$(1 \longleftrightarrow 2) \approx (2 \longleftrightarrow 3) \approx (3 \longleftrightarrow 4)$ (see Fig. B) in an external field H_0 with
average value around 10 G and a variation of several G (rf field $H_1 \perp H_0$).
This effects the transitions $\pm m_F \rightarrow \mp m_F$. Besides these, the following
deuteron transitions[*] are easily effected with almost 100% transition rate
in a low field (appropriately varying for an adiabatic passage) with a few
watts of rf power. With H_1 parallel to H_0 (that means $\Delta m_F = 0$)

$$\left. \begin{array}{l} 2 \rightarrow 6 \\ 3 \rightarrow 5 \end{array} \right\} \quad \text{corresponding to} \quad \Delta m_D = \pm 1$$

and with H_1 perpendicular to H_0 (that means $\Delta m_F = \pm 1$)

$$\left. \begin{array}{l} 1 \rightarrow 6 \\ 2 \rightarrow 5 \\ 3 \rightarrow 4 \end{array} \right\} \quad \text{corresponding to} \quad \Delta m_D = 0$$

$$3 \rightarrow 6 \quad \text{corresponding to} \quad \Delta m_D = 2.$$

The transition $3 \rightarrow 6$ is normally not resolved in a low field
from the transition $2 \rightarrow 5$ but at higher fields (several hundred gauss) this
transition $3 \rightarrow 6$ becomes forbidden and hard to effect like the other
transitions[**] with $\Delta m_D \neq 0$. The fact that the two transitions $2 \rightarrow 5$ and
$3 \rightarrow 6$ are induced in low external magnetic field at the same time is not

---

[*] As long as the external magnetic field is low enough so that F is a
good quantum number one can call all these transitions (except the $3 \rightarrow 4$)
$\Delta F = 1$.

[**] The transitions with $\Delta m_D = 0$ have been described in Saclay as easier
to effect than the $\Delta m_D = 1$ transitions, even in weak external field. The
transition $3 \rightarrow 6$ was not mentioned during our visit (cf. T. W. Eaton,
thesis, Birmingham 1964).

of interest if the beam is not subjected to any further transitions (as in ref. 21, see next paragraph) and/or subsequent multipole separation magnets because the transition $2 \rightarrow 5$ does not change the orientation of the deuterons (ionization in a strong external field).

The strong magnetic field (and consequently high rf power) design in Saclay seems to be conceived originally to avoid difficulties from the stray field of the cyclotron. It is apparently quite practical now to cause the $2 \rightarrow 5$ transition without also producing the $3 \rightarrow 6$ transition (see above) and this is needed in the scheme described in ref. 21.

The value of ΔH is not very critical as was demonstrated in Saclay by the following experiment. Protons, transition $2 \rightarrow 4$, $H_0 = 1000$ G, $H_1 = 2$ G, the variation of ΔH from 0.1 G to 50 G caused the polarization to increase from about 80% going through a maximum of about 100% and again to decrease to about 80%. In a similar experiment the rf field strength H_1 was varied by varying the power from 10 to 70 W. The result was a loss of about a factor of 2 at the limits compared to the maximum. Similar results were obtained for the deuteron transitions $2 \rightarrow 6$ and $3 \rightarrow 5$ with $H_0 = 1000$ G and H_1 varying partly shown in Fig. 22.
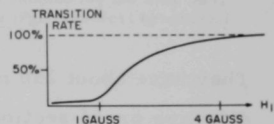
Fig. 22. Effect of rf field intensity on transition efficiency for high field transitions.

One has to be careful of the shape of the field H_1 that the passing atom sees. If the H_1 field has a wrong shape (e.g., too steep a rise or fall, Fig. 23) it can induce unwanted additional transitions.

With deuterons they had previously had a transition rate of about 40% for the $2 \rightarrow 6$ transition with about 70 W in a strong field H_0. With the increased Q value and a power of 400 W they obtain now a transition rate of more than 90%. Abragam's condition would imply
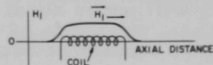
Fig. 23. Field distribution along beam. The steep rise and fall are undesirable as noted in the text.

requirement of several kW of power. This is not needed. One doesn't want the field (H_0) so low that ΔH is such that one gets overlap between the $2 \to 5$ and $2 \to 6$ transitions because of small leakage of the parallel into the perpendicular mode.

Proton transition $2 \to 4$ is not as easy as $1 \to 3$ but this is relative. About 20 W is needed for $2 \to 4$, only a few watts for $1 \to 3$.

Interview with Jacques Arvieux from Grenoble,[*] France (starting his thesis and will be at Saclay for several years). Their ionizer is similar to that at Birmingham but they expect to have a 40 cm long solenoid with a field of about 1000 G. They will use a ring cathode in a form of a Pierce "gun." The cathode is a 1 mm diameter wire. If the arrangement is as shown in Fig. 24, the electrons will be accelerated in the opposite direction to the ions.
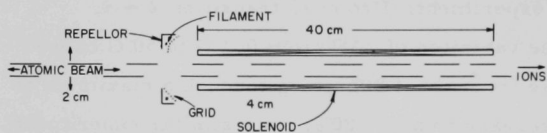
Fig. 24. Ionizer arrangement constructed at Grenoble. The filament is an 8 cm diameter ring operated at -1500 V as is the repellor electrode. The grid is at 0 V. The grid to the right is an electron repellor grid and is also at -1500 V. They have not yet decided whether the atomic beam will be introduced from the right or left in the figure.

They have about 250 mA in the beam (actually immersed in it) but the effective cross section for ionization is increased because spiraling increases the path length. The cathode voltage is $V_k = -1500$ V and the grid is at ground. The unit is very simple but they feel that 8 cm is too large a diameter for the cathode ring. The current is 250 mA all along after the first 10 cm. The current is not zero at the center. They expect between 1 and 10% efficiency (calculated). Extraction is still the problem. They will put in about five cylindrical electrodes. Arvieux is building such an ionizer at Saclay but only 20 cm long and 4 cm in diameter because of pumping difficulties. Electrons will be introduced closer to the axis in the new model. This way, they hope to get more beam current

[*]Others at Grenoble are Prof. R. Bouchez and F. A. Ripouteau.

in the center. The computed value for
the p-p (Fig. 25) distance is 1 cm. At
Grenoble, they have a dissociator, no
6 pole, and the 40-cm long ionizer as
described with an extraction system.

Fig. 25. Elec-
tron distribu-
tion in the
Grenoble ionizer.
The distance
(p-p) is about
2 cm.

They intend it for a 70-MeV proton cyclotron which will be completed in
1967 ± 1 year. If the source is good, they will put it on a Cockcroft-
Walton accelerator to produce polarized neutrons. The dissociator will
use C coupling as at Saclay.

Information on polarized ion source at Lyon (from Arvieux).
They have a 4 pole and have made calculations for 6 poles and because of
the results of this calculation they may build a 6 pole. The location is the
Institut de Physique Nucleaire, Lyon, France. They have a new Philips
Synchrocyclotron of the old type (as in Buenos Aires), 28 MeV. M. Pin.
Professor Feuvrais, Physicist (from CERN) is in charge. They have the
dissociator and 4 pole. The ionizer will be in the synchrocyclotron and
probably of a Penning type.

SPNBE (Delaunay), December 2, 1964

He is working on a source for a Tandem. The source is
similar to that of Keller and Thirion but there are differences in the
mechanical arrangement and in the pumping systems. They use a 1 kW
MOPA at 20 MHz using 1 kW tetrodes in push-pull. They have a remote
control (motor driven) to control the direction of the atomic beam from
the dissociator. The motion is as the generators of a cone. They also
have a longitudinal adjustment. The pivot point is (phantomed) approx-
imately the nozzle. They use a "multivibrator" oscillator.

They have provisions for putting in extra pumping in case
it is needed. There is now a 1800 L/sec mercury pump with an effective
speed of 800 L/sec through the trap and valve. They hope to obtain 10^{-8}

Torr in the ionizer which is a sort of Heil[22] type with a field of 2500 G (Fig. 26). With a residual pressure of 10^{-6} Torr, they have an efficiency of a few times 10^{-3} for hydrogen (this is to be checked again). They use Al gaskets. They expect to try an rf source second. A keep-alive gas may be required such as Ar or similar.
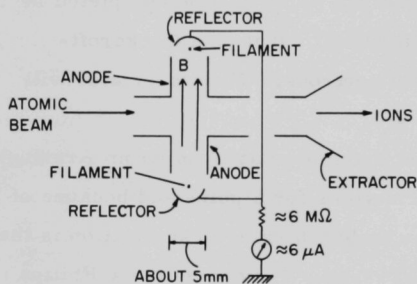
Fig. 26. Cross section of SPNBE ionizer. The anodes are from 3 to 10 kV positive. The filaments are a few hundred volts negative relative to the anode. The extractor is at ground. The magnetic field is between 2000 and 2600 G.
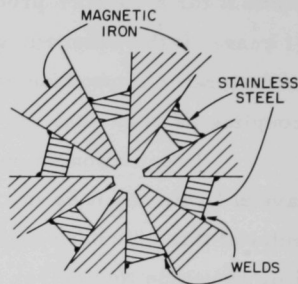
Fig. 27. Approximate cross section of the six-pole lens. The pressure in the central region is about 5×10^{-7} Torr with two 6M3 Edwards mercury diffusion pumps.

Their 6 pole consists of a tube made of magnetic iron welded to stainless steel (Fig. 27). The poles are tapered from a diameter (tip across to tip) of about 7 mm to 14 mm. The coils are outside the vacuum system. The diameter of the magnet will be about 60 cm outside the yoke. This can only be pumped at the ends. Have the usual 30° plus 30° module.

They expect to use foils (carbon) for adding. They also will try direct extraction for negative ions.

[22] H. Heil, Zeitschr. f. Physik 120, 212 (1943).

December 2-4, 1964

4. CERN
    Dr. Louis Dick, Mr. Gregory Kantardjian
    (technician working on the ionizer—worked with Keller)
    Mr. Philip Levy (physicist and engineer on the source)
    Mr. Roger Galiana (engineer on the ionization process)

        The machine on which the polarized proton source is to be
used is a 600 MeV proton synchrocyclotron of 2.5 m radius.[23,24]   There
will be 1.5 m between the end of the 4 pole and the edge of the machine.
That is, from the 4 pole to the ionizing region is about 4 m. The cross
section of the beam at the location of the ionizer is about 2.5 cm diameter.
This is all right for a synchrocyclotron as the acceptance is large. The
4 pole is 6 m long. It separates the single hydrogen hyperfine structure
state 1 ($F = 1$, $m_F = 1$, see Fig. A) and emits a parallel beam of this
state. This means theoretically 100% proton polarization is obtained. The
parallel beam is produced by use of a tapered field, about 4000 G (at the
pole tips) at the entrance, and a few hundred gauss at the exit. They plan
on using rf transitions[4] to obtain a higher experimental degree of polariza-
tion, even without use of a selector diaphragm near or in the accelerator
because the adjustment of this diaphragm (since states 1 and 2 are
deflected differently, a diaphragm can be inserted that will pass state 1
but intercept state 2) is difficult because high background radiation (caused
by the long use of the machine). Therefore, they will replace the diaphragm
with the transition. It is probable that the transition will be placed at the
end of the first 1.5 m section of the 4 pole instead of at the end of the full
(6 m) length as with the greater distance, one loses a factor of 2. Their 4
pole "achromatizes" the beam. They will use a high frequency transition
(cf. Fig. A). They are also planning (as of the date of our visit) to use a

[23]R. Keller, L. Dick, and M. Fidecaro, Helv. Phys. Acta, Suppl. VI. 48 (1961).

[24]L. Dick, Ph. Levy, and J. Vermeu'en, Proceedings of International Conference on
Sector-Focused Cyclotrons and Meson-Factories, Geneva 1963, p. 127.

weak field, low-frequency transition   (1 → 3) at the end of all magnet
sections to reverse the direction of polarization, that is, spin up or spin
down. The frequency will be about 10 MHz, the field about 7 G (using a
figure of 1.4 MHz/G) and the power about 100 W.

There is the problem of the unpolarized background gas.
Dick thinks 95 − 98% of it comes from water. Therefore, they plan to cool
the center region of the synchrocyclotron with liquid nitrogen, that is,
a region about 20 cm in diameter (cf. Basel Report, ref. 1).
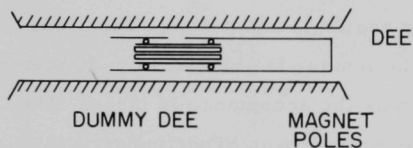
Fig. 28. Arrangement in the test cyclotron
showing the dummy dee which is replaced by
the ionizer unit.

They have a small
cyclotron of about 4.5 MeV (this
uses the magnet from the model of
the synchrocyclotron) for testing.
They replace the dummy Dee with
the ionizer unit (Fig. 28). Where
necessary, they use sapphire as

an insulator as it has good thermal conductivity at liquid nitrogen tempera-
tures and it still maintains good electrical insulation. Without cooling,
about 50% of the ions are unpolarized. With cooling, they have one or two
per cent unpolarized ions in the 4.5 MeV machine.

The use of this ionizer in the machine doesn't affect the
acceleration more than a few percent. With a poor vacuum, a pressure
change changes the percent of polarization. When the background is less
than about 5%, the variation of background with pressure is unimportant.
They expect to have the unit ready to install early in 1965 pending a shut-
down. For ionization in the synchrocyclotron, they have a crossed
electron and atomic beam as they feel that this gives the best results. A
plasma source is not as good (but didn't depolarize according to Dick).
They have an electron beam about 1-in. dia and extract 1 − A of electrons.
An accelerating voltage of a few kV is used but it is possible to decelerate
the electrons. The ionizer has not yet been used with the polarized source.

The field is approximately 10 000 G. There is the problem of the variation of cross section with electron energy. They optimize the electron current and the cross section.

There is an advantage in having the source in the median plane as the second (dummy) Dee potential can be changed. When it had a "balanced" potential, they got twice the ion current. Normally, the single Dee is operated with a dc bias. The dummy is at about the same potential. The usual snychrocyclotron ion source is not on the median plane. Thus, there are strong vertical oscillations (Fig. 29). With the source in the

Fig. 29. Difference in amplitude of vertical oscillations caused by differences in ion injection. With the usual location of source, such as shown at A, the ion path has large vertical oscillations. With the source in the median plane (as B), the amplitude of vertical oscillations is much less.
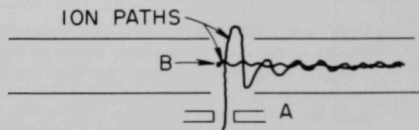
median plane the vertical oscillations are less severe. In the usual accelerator, only 4 to 6 percent of the accelerated beam can be extracted because of the vertical oscillations (or because of the vertical-radial coupling). They will have quite a bit of room in the center of the 600-MeV machine as the Dee gap is 20 cm. It is only about 3—4 cm in the small 4.5-MeV machine.

In 1965 they expect to experiment with a polarized target in cooperation with Abragam (Saclay). They will use nuclear magnetic resonance to determine the polarization of the target.

Every few days, they found their pump oil had been polymerized by the atomic hydrogen. They changed to mercury and replaced all the aluminum parts by ones of stainless steel. This rebuilding cost them one year.

The output is about 10^{16} particles/sec out of the magnet. The aperture of the 4 pole is 1/1000 of its length and they lose essentially only a factor of 4 associated with rejection of three out of four states. They have about 5×10^{19} out of the dissociator. The differential pumping

system is as described in the Basel report. They use a Roots pump as a booster for the mechanical pump.

A temperature of 300°K is assumed for purposes of calculation. Molybdenum oxide pictures appear to support this assumption. The atomic beam is about 30 m diameter at the center of the big (600 MeV) machine.
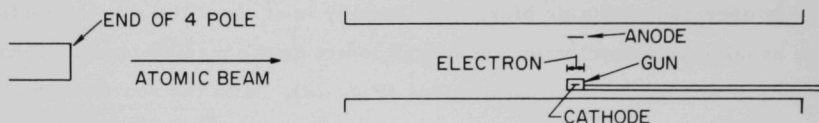
Fig. 30. Proposed arrangement of the polarizer and the ionizer in the 600 MeV accelerator. Details of the electron gun are shown in Fig. 31. The atomic beam is 30 mm in diameter in the ionizing region, where the electron beam is also 30 mm in diameter. The anode-gun separation is 120 mm and the anode-cathode distance is 150 mm. The magnetic field is 20 kG vertical in the figure. The poles have a diameter of 5000 mm and the distance from the end of the 4 pole at the right to the center of the magnet is 5600 mm.

Discussion of the ionizer for the 600 MeV machine (Fig. 30). The vacuum chamber has a volume of 25 m^3, but this region is very "dirty." It is rusty and some experimenters have used ordinary insulated wire inside so there is organic contamination. The cathodes are the largest Philips makes. They come unactivated and are activated by heating to $900^\circ-950^\circ$C for 12 hrs. They are held at 150°C when at atmospheric pressure. In vacuum, 11.3 v, 8.0 A gives 800°C; 13 v, 9.2 A, 850°C; 14.5 v, 10 A, 900°C. These cathodes are obtained through Dr. P. Zalm, Philips Research Laboratories, Eindhoven (reference, letter to Maier at CERN, January 4, 1964). Galiana thinks they are rated at about 10 A/cm^2. They have a diameter of 3.9 cm.

Instead of the Philips cathodes, they have used a double spiral tungsten filament which heats the emitting cathode (a tungsten disk) by electron bombardment. With this double spiral, they get no diffusion of electrons in a 20 000 G field. They base this statement on observation of the heating pattern of the disk. It is probably not too rigorous an exclusion of the existence of diffusion. The filament was supported by

small tungsten feet which held it off from an Al_2O_3 insulator which in turn rested on a water-cooled aluminum plate. They have obtained electron currents of 2 A with the potentials and electrode arrangement as shown in Fig. 31. The distribution of potential in the beam is somewhat as shown in Fig. 32. This shape is due to space charge. If one tried to run the electron energy low, say 280 V (where the ionization cross section is already down to one half its maximum value), one would find that the maximum current would be around 100 mA. Since the electron current depends on the 3/2 power of the voltage while the cross section depends roughly on the inverse 1/2 power (cf. Milan, Page 63) or more closely, $\sigma = V^{-1} \ln 3V$, one finds that the ionization efficiency actually increases with electron voltage (Fig. 33). The currents obtained are limited by their power supplies and are not necessarily the maximum obtainable values (the theoretical limit at 3000 V is about 4 A). They find that de-ionized water with about a 6 cm path is adequate for insulation of the 1 kV anode voltage. They put in some extra elec-

Fig. 31. Elevation of the ionizer. Some of the electrodes such as that at A and the control electrode at B were added later. Electrode B may be used for pulsing. The anode is at +1000 V, the cylinder below it is at +3000 V, A is adjustable, and the cylinder below it is also at +3000 V, all voltages relative to the cathode. The cathode is heated by electron bombardment from the double spiral filament below it. In some of the experiments, the field was 10 kG.

Fig. 32. Potential distribution in the electron beam. The horizontal scale represents a diameter of the ionizer.

trodes. We do not have the voltage on A. The electrodes are Mo. The heater (filament) takes 48 A at 40 v and is driven by a 2 kW 3 kHz transistorized, transformless amplifier. They have not yet used the ionizer with the proton beam.

IONIZATION
EFF.
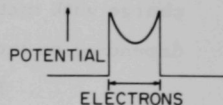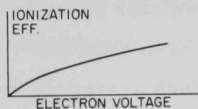
ELECTRON VOLTAGE

Fig. 33. Ionization efficiency
as a function of the applied
electron voltage. Operation
in the electron space charge
limited condition is assumed.

On the question of ion trapping, Levy says that it has already caused trouble in cyclotrons.

We met Klaus Haberracker from Erlangen (with Prof. Mollwo). He had some comments on the use of ZnO crystals or crystal to detect hydrogen atoms (cf. Erlangen).

The source described above apparently has a virtual cathode. They have found that the virtual cathode almost disappears when the nitrogen traps are too warm. This information was elicited when we inquired about positive ion neutralization of space charge. When the virtual cathode decreases, the electron current increases. This goes on until there are sparks. Levy also mentioned the potential depression in the beam as drawn on the previous page. Galiana thinks that possibly one can get separation between two electron beams less than the diameter of the beam and that it might be possible to put six beams in the space as we plan. This was in response to our inquiry about the apparent incompatibility of the current limitation of e.g., Pierce,[25] p. 154, Eq. (9.32) and the idea of making the field strong so that the beam diameter is small and then putting several beams in the space where only one could be put with a weaker field. In order to do this, one "must" form the electron beam outside the magnetic field. The possibility of putting coils on the (iron) pots was mentioned. They suggested that we try to neutralize the space charge with metallic (but not Hg because of the Au gaskets) ions instead of depending on the hydrogen ions.

The discussion led to a sort of picture of the performance. I am not sure whether this is based on their measurements or is merely my conjecture. The general idea is that of a container with a large hole near the top. If water flows into the tank at a certain rate, initially no

---

[25] J. R. Pierce, Theory and Design of Electron Beams, 2nd edition, D. van Nostrand, New York (1954).

water will flow out. As the level
reaches the hole, water will begin to
emerge and if the hole is large enough,
ultimately the outflow will equal the
influx (Fig. 34). If the electron beam
is pulsed, presumably all the ions can
be drawn out but then no ions will be
available after the electron current is
resumed until the "tank is filled." Thus,
the average current will not be greater
than with dc operation. A second type
of ionizer they have considered is a
"quadrupole," that is, two cathodes
and two anodes (Fig. 35). It
operates as a "trochoidal" mass
spectrometer. Ions were not
drawn out if the energy was too
low. The source caused de-
polarization.
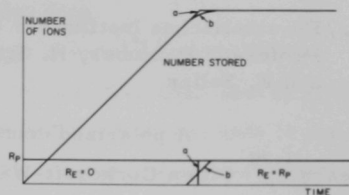
Fig. 34. Representation of the extrac-
tion of ions from an ionizer as a
function of time. The sharp corners
(a) represent an idealized situation
where the conversion from a storing
to an emitting state is very abrupt.
The rounded curves (b) represent a
more reasonable situation where the
trapping effect weakens gradually as
the tank becomes "full." R_p is the
rate at which ions are formed. R_E
is the extraction rate.

Fig. 35. Simplified diagram
of the quadrupole ionizer.
The curves connecting the
anodes and cathodes re-
present magnetic flux lines
and also electron paths, if
the diameter of the spiral
is small.
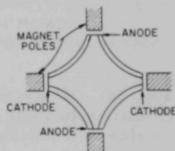
Some miscellaneous comments. (1) Teflon "burns" in the
atomic hydrogen in the dissociator discharge. (2) They did an experiment
on stochastic acceleration (unpolarized) and had approximately a 50% duty
cycle. Possibility of time-of-flight separation of p-p and p-d scattering.
They could use a solid state detector.

5. Physikalisches Institut der Universitat Basel
   Professor P. Huber, H. Striebel, H. Rudin,
   and F. Seiler

A polarized deuteron source has been working for several years[1,26] with a Cockcroft-Walton accelerator (600 keV) and is described in connection with several experiments done recently[27-31] (see there for earlier references). In addition, there is another complete source for testing and development work.
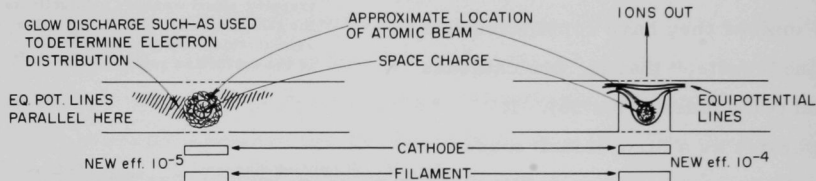
Fig. 36. Old ionizer.[1] The electron distribution was estimated from the visible glow in the discharge. Efficiency about 10^{-5}.

Fig. 37. The modified ionizer. In both cases, the atomic beam is indicated by a solid circle. The diameter of the space charge is smaller in the new ionizer so one expects a higher efficiency. The efficiency is about 10^{-4}.

They have modified the electron gun and ionizer described in ref. 1 and earlier publications (Fig. 36). By adding shields, the electron spread has been decreased and the electron space charge localized in the position of the atomic beam (Fig. 37). The intensity increased by a

[26] H. Rudin, H. R. Striebel, E. Baumgartner, L. Brown, and P. Huber, Helv. Phys. Acta 34, 58 (1961).

[27] F. Seiler, E. Baumgartner, W. Haeberli, P. Huber, and H. R. Striebel, Helv. Phys. Acta 35, 385 (1962).

[28] W. Trächslin, E. Baumgartner, H. Bürgiesser, P. Huber, G. Michel, and H. R. Striebel, Helv. Phys. Acta 37 216 (1965).

[29] Same authors as Ref. 28, in press, Helv. Phys. Acta.

[30] H. Bürgisser et al. (abstract) in press, Helv. Phys. Acta, full report in preparation.

[31] H. Rudin et al. (abstract) in press, Helv. Phys. Acta.

of about $2\frac{1}{2}$ and the polarization (P_{33}) increased from -0.20 to -0.28 because of the decrease of unpolarized background.

The targets are at high voltage in the Cockcroft-Walton. The detector signals are discriminated and scaled down then sent to ground through lucite light pipes. The transmitter is merely a neon bulb in the scaler output, i.e., the usual indicator light. There are eight separate light pipe channels. They use five counters to measure neutron angular distribution. They measured the T, d reaction $T(d, n)^4He$ up to about 600 keV.[28-31] This is the mirror reaction to $He^3(d, p)He^4$) which has been measured between about 0.3 MeV and 3 MeV by L. Brown (DTM, Carnegie Institute, Washington, D.C.), Hans A. Christ, and H. Rudin (both University of Basel) at the Carnegie Institute. Their results will soon be published. (See below for other experiments in progress at the University of Basel about polarization phenomena.)

H. Rudin has built an rf transition unit to effect adiabatic passages.[4] He followed the outline given in ref. 29, that is, to operate in a field of about 150 G with a frequency of about 400 MHz. They have built a 10 w, 400 MHz oscillator. For the 3-5 and 2-6 transitions, H_1 is to be parallel to H_0. Thus, the obvious solenoid arrangement must be modified (Fig. 38).

An external electromagnet supplies 150 G for the 3-5 and 70 G for the 2-6 transitions. It has a gap that varies from 47 to 43 mm. There are two coils of 1100 turns each which gives 1100 A turns at one half ampere. The transitions were

Fig. 38. RF coil design for H_1 parallel to H_0 (3-5 and 2-6 transitions).

practically complete and a P_{33} of -0.83 ± 0.03 and +0.75 ± 0.05 were measured. Weak field transitions ($m_F \longleftrightarrow -m_F$) were also successfully induced.
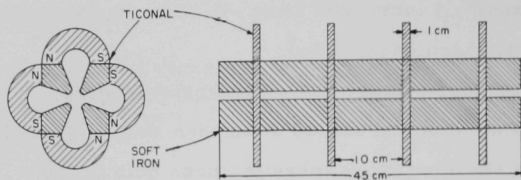
Fig. 39. Cross sections of the PM 4 pole. The left view is in a plane perpendicular to the motion of the atomic beam and the right view is in a plane parallel to the beam motion. The over all diameter is about 21 cm and the aperture is 1 cm. The units are made up of 1 cm thick permanent magnets separated by 10 cm. The over all length is 45 cm.

There are two quadrupole units, each 45 cm long as they believe they can get better pumping with separate sections. They are made of several horseshoe permanent magnets as shown (Fig. 39). These are Ticonal and were obtained from von Roll. There are 4 × 4 or 16 magnets per 4 pole. The beam intensity with one 45 cm section was the same as with two sections but the background (molecules from the dissociator) was larger with the single section.

For a strong field ionizer, one can use a filament as the electron source as one doesn't need to worry about the stray fields due to the heater currents as one must with the weak field ionizer. This is the reason for using the "dispenser" or other indirectly heated cathode for the weak field ionizer. At Basel they use for strong field ionization a source similar to that described by M. V. Ardenne.[32]

They produce the magnetic field in the ionizer by means of a split solenoid. With 6000 AT /coil, they have about 400 G in the ionizing region. They also want to try a cylindrical filament for the weak field ionizer.

Fig. 40. Section of ISOLA AG insulators.
They have rotational symmetry about the axis.

The insulators they use for these units are commercial ceramic ones, available from Isola AG., Breitenback SO, Switzerland. They are about 8 mm diameter (Fig. 40). Striebel and Rudin also tried a

[32] M. v. Ardenne, Phys. Zeitschr. 43, 91 (1942).

plasma source (Fig. 41). The intensity was low, only about half of the first unshielded source (Fig. 36). There is an axial field of about 10 G. The effect of a change of the magnetic field from axial to perpendicular to the direction of extraction was inconclusive.

The efficiency was a few $\times 10^{-5}$. The capillary system was used to prevent backstreaming of the discharge gas mixture into the polarizer. They varied the capillary system and found no difference with and without it (in degree of polarization). The only pumping was through the inlet and the extraction channel. Without the

Fig. 41. Sketch of the plasma ionizer. The polarized atomic deuterium beam enters from the left through the capillary system C. The extraction channel E has a variable voltage up to 7000 V. The rf excitation is at about 20 MHz. The pyrex system was cleaned with H_2F_2. The discharge gas enters through the tube at the bottom.

capillaries, the pumping speed was about 44 L/sec of hydrogen. The lowest usable pressure was about 10^{-3} Torr. The normal discharge gas (Hilfsgas) was a mixture of hydrogen and either argon or helium. For example, with a few microns of 10% H_2 and 90% He, and a beam of 10^{15} atoms/sec, they got the effect shown in Fig. 42. If Teflon was introduced either as an emulsion to coat the glass or as a Teflon sheet inside the glass, they got the results shown in Fig. 42. They tested the polarization with the d, T reaction and found that the polarization was almost completely destroyed in this source.

The extraction efficiency increases with increase of extraction voltage but one has breakdowns, so about 7 kV is the useful limit. They still have hopes of heating the tube. Probably in the far future.

They mentioned beats between the dissociator and the discharge oscillators. They use about 100 W. They calculated a field of a few gauss ($B^2/8\pi$ = power $\times$ time/volume). In a strong magnetic field,

Fig. 42. A time lag in response of output of the plasma ionizer. The beam is turned on at A and turned off at B. The dots are at ten second intervals which was the counting interval. N is the number of neutrons from the T(d, n)α reaction. Note that the counting rate returns to the background level about 40 seconds after the beam is shut off.
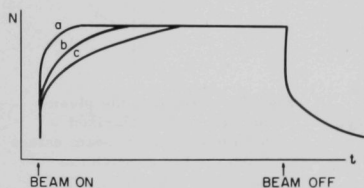
Fig. 43. Effect of Teflon and of Ar vs He or H_2 as "Hilfgas" for the plasma ionizer. Curve (a) shows the rate of rise with clean pyrex using H_2 and He. Curve (b) shows the same for a Teflon coating and Ar or He. (c) is for clean pyrex and Ar or He. N is the number of neutrons from the T(d, n)α reaction.

the discharge might work at 10^{-5} Torr because of the Penning effects.

They (Striebel) are building another source (see below) for installation in the dome of an existing 1 MV Cockcroft-Walton. They also want to improve the ionizer by use of the cylindrical cathode structure on the 600 keV machine.

A discussion of ionization efficiency, defined as,
$\eta = I_e S P d(B) \ell \epsilon$, where P is the reuse factor for electrons, S is the spiraling factor for the electrons (this increases the effective current), d is the divergence factor of the electron beam due to the magnetic field B, ℓ is the length of atomic beam path in which ionization occurs, ϵ is the extraction factor, and I_e is the electron current.

The efficiency η is one factor of interest, but the emittance of the beam is also important. This is a measure of the beam quality. $E = a\Omega$ where a is the area of the beam and Ω is the solid angle of a. The electron current I_e depends on the cathode. P depends on the geometry and on B. Factor d also depends on B, while a influences E. Striebel hopes to use space charge to influence drawing out of the ions. The spiraling factor S is also a function of B. Striebel mentioned the natural limitation on the acceptance of lenses to be used with beams which may have azimuthal components (Fig. 54).

Fig. 44. (above) Apparatus used for measure-
ment of ion trapping in space charge. The
collector is a Faraday cup which is used for
emittance measurements also.
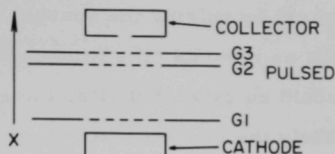
Fig. 45. (below) Voltage on grid number two.
The peak V_2 is about 30 V above the mini-
mum value of V_2. The negative pulse is
about 0.1 us while the "on" time or positive
going pulse has a variable length which
depends on the repetition rate.
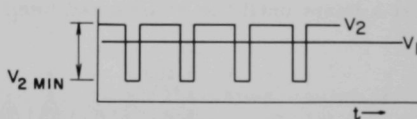
An experiment on ion trapping in space charge was done in
the residual gas but was not published. The electron beam is kept con-
stant (Fig. 44), grid G2 is pulsed as in Fig. 45. Distance x is measured
from cathode toward the Faraday cup. The pulse is of fixed duration (0.1
μs) but of variable frequency, 200 kHz to 2000 kHz (a factor of ten). The
average beam current in the Faraday cup is independent of frequency.
This is only true as long as the frequency is not too low. They did get
some variation at lower frequencies. At a suitable frequency, the average
current was constant and equal to the value for v_2 = constant = $v_{2\,minimum}$
(Fig. 46). This shows that ions are trapped in the negative space charge.

Fig. 46. Potential variation with time and
distance in apparatus of Fig. 45. The
lower curve (a) is with the potential on G2
constant at V_2 minimum. The middle one
(b) is for G2 pulsed as per Fig. 45 at a high
rate (see text). The upper curve (c) shows
the effect on the potential distribution with
slow pulsing so that there is time for the
region beyond G1 to be filled with ions (a
few μs). These ions went backwards until
the pulse arrived. V is the potential.
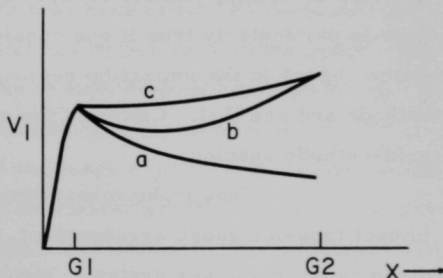
One gets bunching so <u>for a pulsed accelerator</u> one would gain (at least in efficiency) by pulsing the source. With a continuous machine one would not gain as it would take time to "fill the tank" (cf. CERN, p. 42) before ions could be extracted after the electron beam was turned on. That is, ultimately the number that can be extracted under dc conditions should be equal to the number being formed, since the <u>ions do not recombine</u>.

In another unpublished experiment, they frequently found that they had no D^+ after reassembling the source. They were unable to get a beam until the source had been dismantled and again assembled.
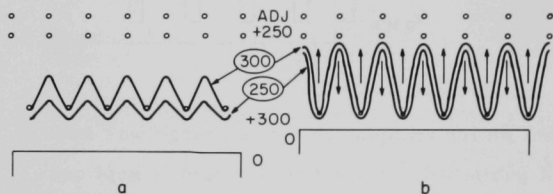
Fig. 47. (a) Potential distribution with cathode normally positioned. (b) Potential distribution with cathode unusually close to space charge grid. Note how the cathode potential "penetrates" into the ionizing region between the grid wires so that ions are attracted to the cathode and are lost.

They finally concluded that the distance from the cathode to the first grid was very critical. Figures 47(a) and 47(b) show how the distance between the cathode and the nearest electron accelerating grid influences the potential and field distribution in the ionizing region. To obtain large electron currents one wants this distance to be short but if it is too short [Fig. 47(b)] the ions created between the two grids (at 300 V and 250 V) in the ionization region are not drawn in the intended direction, namely towards the 250 V grid but rather to the cathode. This is particularly true if one considers the presence of the electron space charge in the ionization region. In this case, all ions go to the cathode and are lost. Compare the effect in a triode of close vs wide grid-cathode spacing.

They make measurements on the atomic beam with an impact tube-ion gauge arrangement. They remove the magnet (or use the dissociator in another system), measure the intensity, then combine the

dissociator and mag-
net and make intensity
measurements at the
same distance from
the dissociator (Fig.
48). They also make
measurements at
different distances
without the magnet to
check the inverse
square law. It checked.
They measured the
angular distribution
from the dissociator
which uses a capillary system.
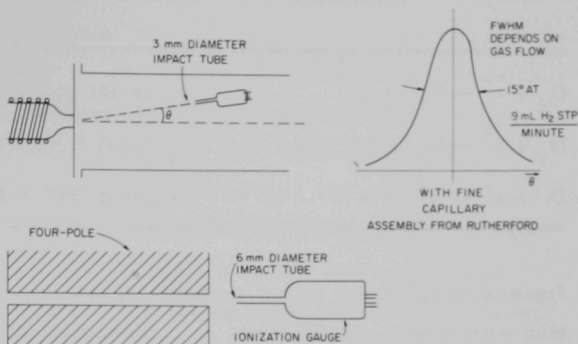
Fig. 48. (a) Arrangement for measurement of atomic beam
distribution. (b) Distribution of atomic beam at 9 ml
hydrogen STP per min, through fine capillary assembly
from Rutherford. The full width at half maximum depends
on the gas flow. (c) Measurement of beam which has
passed through the 4 pole.

The spread at the end of their 4 pole is about $\pm 0.6^{\circ}$ (they
accept $\pm 1^{\circ}$ at the inlet). They measured the beam structure with an ion
gauge probe. The probe ram tube was about 1 beam radius in diameter
and about 100 mm long. The diameter of the tube was 6 mm and the beam
is about 1.6 cm diameter. The change of pressure in the gauge was of
the order of 2.5×10^{-6} Torr. They compromised on the length and
diameter of the probe tube and on speed of response and background (use
of term microtorr).

Striebel estimates that they have about 50% dissociation.
It is higher at first then drops in about one or two days to the above. He
quotes cross sections to show that the neutral molecule to atomic ion
(plus) cross section is 25 to 50 times less than the neutral atomic ion
cross section. Striebel is afraid of too large a beam of molecules in the
ionizer because he thinks the atomic ions observed from H_2 which form an
unpolarized background come from the dissociation of the molecular

TABLE III. [33,34] Ionization Cross Sections

$D_2 + e^- \rightarrow D_2^+ + 2e^-$	σ_2 is not of interest as D_2^+ is removed by the Wien filter
$D_2 + e^- \rightarrow D + D^+ + D e^-$	σ_1 about 5×10^{-19} cm^2 at 300 eV
$D + e^- \rightarrow D^+ + 2e^-$	σ_0 about 350×10^{-19} cm^2 at 300 eV

fraction of the beam on hot surfaces of the ionizer and subsequent ioniza-tion with large cross section. [33,34] They have about the same amount of molecular hydrogen diffusing as in the beam. They feel that Vac Ion pumps are not satisfactory as they load up with hydrogen and then desorb lots of it. They wait about two hours for the ion pumps to clean up after a burst. At about 4×10^{-6} Torr, one needs oil or mercury pumps with liquid nitrogen baffles and traps.

In an unpublished experiment on desorption, the atomic beam was turned on and off. From the initial drop (Fig. 49) when the beam is turned off, one determines the effective background in the ionizer. This gradually decays to the value it had be-fore the beam was turned on. L. Brown (DTM Washington) has two chambers so he doesn't get this effect. He has $P_{33} = -0.30$ vs the value of -0.28 observed here. This indicates that differential pumping is important.
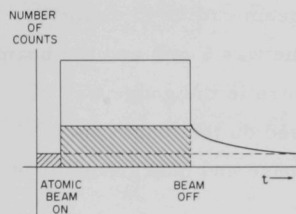
Fig. 49. Experiment on desorp-tion. The shaded area represents the effective back-ground. Note that it is larger than the value read before the atomic beam was admitted. The background decays to the initial value slowly after the beam is cut off.

NUMBER OF COUNTS

ATOMIC BEAM ON   BEAM OFF   t →

They used a small Roots pump in connection with a fore pump as this is cheaper than a large diffusion pump or a Roots that would

[33] W. L. Fite and R. T. Brockman, Phys. Rev. 113, 815 (1959).

[34] H. F. Newhall, Phys. Rev. 62, 11 (1942).

operate against atmospheric pressure. We understand that the Leybold
system is more expensive than the Heraeus, because the former operates
against atmospheric pressure. They suggest using only the beam catcher
diffusion pump with trap, not the extra one we had planned on the side.
Haeberli made the system bakeable and got UHV without inlet gas.

There is the question of what to cool and what not to cool. In
the first Basel gun, everything was cooled. Then a wandering electron
beam would cause outgassing. Therefore, they now only cool where
necessary, that is, if the item is meltable or might be mechanically un-
stable, if there is any possibility of electrons hitting. They run the
cathode at wall potential so that the electrons do not hit the wall with much
energy. The extraction electrodes can be hit so they make this part up
with good ceramic insulators so the whole thing can be baked. It may be
necessary to shield the insulators.

Details
of grid construction.
If the grid wires are
spot welded, the grid

Fig. 50. Details of the construction of the grids.

will deform on heating. They use clearance holes and merely bend the
wire as shown in Fig. 50 (no welds). When the wire expands, it can
remain straight while the ends have room to move into the hole. With 0.2
to 0.5 mm wire, would use a 1 mm or larger hole.

H condenses above liquid nitrogen temperature, that is, it
sticks on a pyrex wall. There is a question as to what would happen on
Teflon. Cooling with dry ice doesn't affect the beam (in response to our
idea of cooling the capillaries).

They tried to estimate the number of returning electrons
which were observed by the glow they cause as before (Fig. 51). The
glow is weak indicating that few electrons penetrate. Only these (about
10% of the total) oscillate and return to the main ionization volume so most
are lost to sides [note absence of the shields which have been added to
latest version (cf. Figs. 36 and 37)].

The cathode-pellets (ref. 27) were produced by Cerberus, Mannedorf ZH, Switzerland, but they have discontinued production. At Erlangen, they hope to find other suppliers (cf. Erlangen, p. 85).
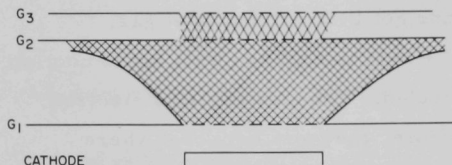
Fig. 51. Location of the glow which was used to estimate the number of oscillating electrons. The glow is strong between G_1 and G_2 and weak between G_2 and G_3.

In recent experiments the tensor and vector efficiencies of the $^6Li(d, a)a$ reaction have been measured by Bürgisser et al.[30] They found the vector analyzing power to be practically zero while the tensor efficiencies correspond nearly to an S-wave resonance in a 2^+ state. In the $^6Li(d, n\gamma)^7Be$ reaction Michel et al. found vanishing tensor efficiencies and vector efficiencies of up to 35%. Measurements of the anisotropy and asymmetry of the n from the $^7Li(d, n)$ reaction (Schier et al.) are in progress. Again the tensor efficiency is probably zero while the vector efficiency is of the order of 0.12 at the maximum. Lehmann and Seiler are building a polarized He^3 target to study the $^3He(d, p)^4He$ reaction. With a polarized target and a polarized beam, they expect roughly twice the effect one would get with a random target. They expect only about 20% polarized target at first. May use helium optical pumping with circularly polarized light from helium as shown working by others. An external magnetic field is needed. At Rice University[35] without a charged beam, they had up to 80%. The beam depolarized the target (gas target) i. e., 40% without the beam, down to 20% with beam. They will again take up the (d, d) reaction by the end of summer, 1965. $D(d, n)^3He$ and $D(d, p)^3H$,

---

[35] G. K. Walters, F. D. Colegrove, and L. D. Schearer, Phys. Rev. Letters **8**, 439 (1962); G. C. Phillips, R. R. Perry, P. M. Windham, G. K. Walters, L. D. Schearer, and F. D. Colegrove, Phys. Rev. Letters **10**, 108 (1963).

Rudin, Petitjean, Schieck, and Striebel, preliminary experiments to show
that the effects are small and that the background might cause trouble.
Brown and Christ did from 600 keV up. They hope to do up to 600 keV.

They studied the idea of making a polarized ^{6}Li source,
but dropped further consideration because of a lack of manpower.

Some features of the polarizer used on the 600-keV
machine. They have only a 200 W rf supply for the dissociator, not one
kW as so many experimenters have. They have a Helmholtz coil system
on the ionizer to supply the (weak) guide field (needed to maintain polari-
zation during ionization). With three sets of Helmholtz coils at right
angles, the direction of polarization can be shifted at will. However, this
requires readjustment of the ion sourse because of the influence of the
magnetic field on the electron distribution and on the ion trajectories.
By using longitudinal and transverse polarization one gets "shift"
measurements with the same philosophy that applies to the Saclay (q.v.,
pp. 26, 30) spin flip.

A tritium target is used as a monitor. They remove the
experimental target from the beam about once an hour and record the
output from the tritium target for about five minutes. The T target is
always in position and the experimental target is placed in front of it. It
can be repositioned to about $\frac{1}{2}$ mm. The target area is pumped down
through the high voltage column. The pressure is a few $\times 10^{-5}$ Torr.
They have about 3 kW available in the terminal which supplies the bending
magnet and the electronics.

As indicated earlier, the targets are at high voltage and the
signals are sent back to "ground" by means of light pipes. These are now
single lengths (2.2 m) of Perspex, 1 cm diameter. It is necessary to
check the material for transmission as some samples absorb in the green
or yellow. They have no cross talk and did not have with the earlier light
pipes that were made of two lengths of rod. The necessary pulse height

discrimination is done in the terminal, as their attempts to transmit
pulse heights directly failed because the characteristics of the neon bulbs
change with time. Use of pulse height frequency conversion is limited
because of the frequency limitation of the bulbs. All pulses are passed
through one decade scalers and the last flip-flop bulb feeds the light pipe.

The 600 kV high voltage unit (which will supply up to 5 mA)
is about three years old. The same company makes Cockcroft-Waltons
up to about 4 MV.

Design of the small machine for use at 1 MV. It will be
about 1.30 m long with an overall height of 0.85 m and about the same
breadth. There will be a dissociator, a 45
cm long PM 4 pole, HF transitions, and a
strong field ionizer. They will save space
on the dissociator tank by using a side dis-
charge (Fig. 52) for the capillary system.
They have tried this and it works. For
energizing the whole source, they need a
motor-generator set of 10 kW power.
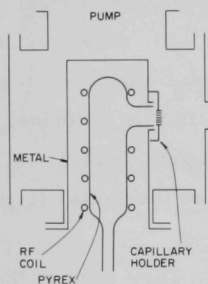
Fig. 52. Arrangement of
dissociator to be used with
small polarized ion source.

They prefer to have the dis-
charge in the region of the capillaries, not
at a distance. (This taken together with other statements about the
inadvisability of having Teflon in the discharge means that capillaries of
Teflon would be undesirable.) They had an earlier side capillary system
using the "U" shaped tube idea as in Fig. 53. It worked well. Note that
this is not the usual arrangement of a small tube as this is inductively,
not capacitantively coupled (Fig. 54).
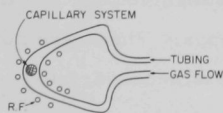
Fig. 53. Earlier disso-
ciator system.

An experiment to obtain polarization
by optical pumping was described to us by Striebel
who, however, did not participate in the experiment.
They tried optically pumping in rubidium beam
then by collision to exchange spins with hydrogen.

Fig. 54. Permissible acceptance of lens. On
the outer extremity, no radial velocity
(positive) can exist or the particle will be
lost. Some azimuthal velocity is permitted.
Somewhat inside the lens "stop", some
radial velocity and even more azimuthal
velocity will not result in loss of the particle.
The net result of this is that the $\dot{r}$ vs $r\dot{\phi}$
curves is restricted as shown.
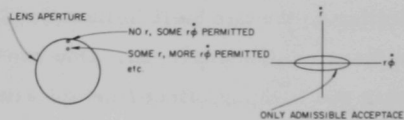
They got 80% of the rubidium polarized, they added H_2 and kept the 80% in
the rubidium. When they added atomic hydrogen instead (by switching the
dissociator on), they observed a decrease of polarization in the rubidium.
This decrease was a function of the amount needed. They ionized the
hydrogen from the cell and found no polarization. Most of the hydrogen
coming out was molecular. Why had it recombined? They tried various
coatings on the walls. There is always a layer of rubidium on glass so
get recombination by surface absorption of H. They could have heated the
cell but the experiment was stopped before this. One needs a coating for
rubidium pumping and heating would destroy this. A rubidium coat is sup-
posed to prevent spin relaxation. With rubidium vapor, e.g., at 5×10^{-5}
Torr, 10 cm, a large loss of beam was found.

We met Professor Gianni Poiani of the Instituto di Fisica,
Universita Trieste, Italy.

They hope to build a polarized ion source (for both p and d)
for the Tandem at Padua. They have a 5 MeV Van de Graaff but will try
to get a Tandem. Professor Claudio Villi of the Instituto di Fisica, Padua,
theoretician, is head of the department.

They need money for the source and for the Tandem. They
probably will buy the Tandem (but note the difficult exchange and the fact
that Milano built its cyclotron). Poiani estimated that it would take a few
people, 10^7 Lire, and about a year. The pumping system would be about
half of the cost (10^7 Lire is about $16 000). There are some Italian pumps
but they are as expensive as Balzers or Edwards and the delivery is slow.

They will use a usual array of a dissociator, a 4 pole (PM) 80 cm long made up of 2, 40 cm long units, a strong field transition similar to the one built in Basel, and a strong field ionizer. Poiani thinks ionizers can be improved. One can get an electron plasma of high density using the Penning effect (the spiraling reuse of electrons, not the original Penning effect).

Milan   December 9-10, 1964

6. University of Milan
   Professor G. Tagliaferri
   Nicola Merzagora (full time on POLISO)
   Alfredo Luccio (mostly on cyclotron)
   C. Succi (mostly on cyclotron—oldest on cyclotron)
   Bruno Candoni (full time on POLISO)

The polarized proton source[36] is intended to be connected to the 45 MeV proton cyclotron of the University of Milan which is near completion [fixed frequency azimuthally varying field (A.V.F.) 86 cm pole radius strong focusing Thomas type[37-41]].

The source was started at ISPRA in 1958; ISPRA is now part of EURATOM (Luccio and Succi). The work on the source was stopped to build a cyclotron. They began again in 1962 with Merzagora. They have a vacuum tank (paper in Nuovo Cimento[36]) and a 6 pole without iron, which is formed by 6 water-cooled 2.75 m long tubes arranged symmetrically

[36] A. Luccio, N. Merzagora, and C. Succi, Nuovo Cimento 33, 1710 (1964).

[37] A. Luccio, G. Pavanati, F. Resmini, C. Succi, and G. Tagliaferri, Nucl. Instr. Methods 18, 19, 74 (1962).

[38] M. Castiglioni, M. Fois, A. Luccio, F. Resmini, C. Succi, and G. Tagliaferri, CERN 63-19, p. 245 (29 May 1963).

[39] E. Acerlei, M. Castiglioni, M. Fois, A. Luccio, N. Merzagora, F. Resmini, C. Succi, and G. Tagliaferri, Stato della constructione del ciclotrone . . . ; Bologna, Tipografia "Monograf," 1964.

[40] G. M. Budyansky, Yu. A. Zavenyugin, N. D. Federov, and V. A. Khrabrov, 1960. Plasma Phys. 1, 149.

[41] F. Lobkowicz and E. H. Thorndike, Rev. Sci. Instr. 33, 454 (1962).

around a center
(see Fig. 55) and
carrying a current
of about 2000 A (3V)
in alternate direc-
tions.[42]   They use
a homopolar genera-
tor with a high con-
stancy of angular

Fig. 55. Field resulting from current in cylindrical conductors. The diameter of the conductors is 0.8 units, the "aperture," 1.0 unit, and the centers of the conductors are on a circle of 2.0 units diameter (after Freiburg, ref. 42).

momentum to create the current. At present there is no longitudinal field
gradient (the conductors are strictly parallel) but they have means of
adjusting the assembly to change the spacing and they could taper the field
if they wished. The excitation is continuous, not pulsed. The field is
about 200 G. A general view is given in Fig. 56. At present they expect
to do only protons.

The
dissociator operates
at a frequency of
about 20 MHz (Fig. 57).
The output of the dis-
sociator is from three
sets of angular slits in
pyrex. They merely
clean with alcohol, no
dichromate or H_2F_2.
They are testing other

Fig. 56. Section through the polarized ion source. (1) Vacuum chamber, (2)dissociator, (3) iron free 6 pole lens, (4) molybdenum oxide plate. The distances are in mm (after Luccio et al., ref. 36).

materials. The slits are made by an ultra sonic technique. They have
studied a system with a Laval nozzle. They separate a single level by
use of an axial hole to discriminate against state 1 in favor of state 2.

---

[42]H. Friedburg, Zeitschr. f. Physik 130, 493 (1951).
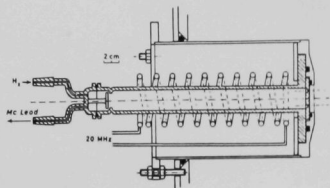
Fig. 57. Dissociator (after Luccio, ibid.)

They photographed a molybdenum oxide target and tried to make micro-densitometer measurements of the photograph. They felt the results were not good. They have not yet had a measured polarized beam.

They made their molybdenum oxide deposits by evaporating from molybdenum in $10^{-1} - 10^{-2}$ Torr of air. The ionizer is being designed. They have a beam of about 10^{13} atoms/sec over an area of about 1 sq cm. They hope a Laval nozzle (supersonic flow) with a quartz coating will increase the intensity of the beam. They have increased the intensity by using a booster pump in the first stage. They have not planned on rf transitions yet. They expect to inject the beam almost along the median plane of the cyclotron. The polarized beam is to be well collimated about 1 cm diameter. They expect to use an extra 6 pole with iron pole tips as a lens to produce a parallel beam for introduction. They have made a phase plot (theoretical) and they calculated a divergence of about 20 mrad. They expect to cool the ionizer region with liquid nitrogen. The field is about 8000 G at the center and the gap (iron to iron) is about 11 cm. The ion source is between 2 and 3 cm high. It is about 1.6 m from the end of the magnet to the ionizer. They have an axial hole in the yoke so that they have the possibility of axial injection. However, the hole does not extend through the pole face and they may have the problems CERN has if they decide to try to put the hole in later (excess radioactivity).

They have a mock up of the vacuum tank system for ionizer tests. This is actually a 1:5.26 scale model of the main cyclotron. They can obtain a field of 8000 G in the center (same as the large machine). The ionizer test unit can be liquid cooled. They claim that the residual vacuum in their cyclotron is good, less than 10^{-6} Torr. They hope for better than 5×10^{-7}. They are considering the problem of depolarization

during acceleration due to residual gas. Also, the possible loss of
polarization during injection. They expect an ionizer efficiency of
about 10^{-3}, so with a net effect cyclotron duty cycle of 1%, they would
get about 10^8 ions/sec from a beam of about 10^{13} atoms/sec.
Pierce[25] type gun for use in a magnetic field. They estimate they have
about 75% dissociation. To optimize the rf coupling they looked at the dis-
charge with a large (≈ 1 m circle) ultraviolet spectrograph with good
resolution. With Kodak P1200 Super pan Press Plates, exposure time
of a few seconds was adequate. It was easy to recognize with the naked
eye the case when the H_β was much stronger and the molecular bands
displayed the same intensity.

The pump system for the dissociator contains among other
pumps (see Fig. 56) a 10 000 L/sec oil diffusion pump from "Officine
Gallileo" (Firenze, Italy, Via Carlo Bini 44) in series with a 1800 L/sec
booster pump from Leybold. TERESSO 56, an "ordinary" motor oil, is
used in the booster. The total pump capacity is 2—3 Torr L/sec but for
the time being they use only 1/10 of this capacity. A single rotating fore
pump of 200 m^3/h serves all diffusion pumps. For the diffusion pumps
they use Diffoil and for the rotating pump Rotoil both from Officine
Gallileo, Firenze, Italy.

For "non-recombining" surfaces, they evaporate SiO, or
SiO_2 on Al, brass or stainless steel. Possibly Al oxidized by electrolysis
would also work for Laval nozzles, etc. They have tried DeGussit
(Ceramic, Lava). They have only started to measure the recombination
rates.

It will probably take them about eight months more to finish
the cyclotron. Then about 1 or 2 months more to obtain an internal beam.
They have had trouble with an internal water leak. The POLISO will be
ready to put on the cyclotron in about a year, probably at the beginning of
1966.

For the pressure transducer in the beam measurements, they use a "Pirani" with small thermistors,[43] about $\frac{1}{2}$ mm diameter. These are Philips (catalogue section on N.T.C. resistors, 1963 edition) B8 320 06/P 100K or B8 320 02/P · · · (where the dots are replaced by the desired resistance, e.g., 100 k ohms). I am not sure at what temperature, but presumably room temperature. They come sealed in glass which is removed at Milano.

For the pressure transducer, they have tried a condenser manometer, ion gauge types (Leybold-Alpert type) and a Pirani with two thermistors as above. No good results have yet been obtained.
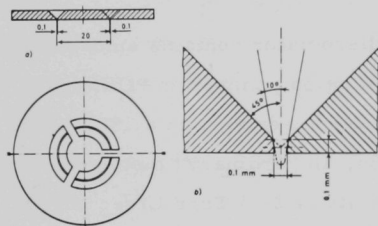
Fig. 58. Detail of the dissociator diaphragm (a) general, and (b) outline showing tool shapes used to produce the grooves. The 45° (half angle) bit is used first and then the 10° bit (after Luccio, ibid.)

The slit system in front of the dissociator is produced by ultrasonic etching. The shape shown (Fig. 58) is formed by first making a cut with a 90° tool and then finishing with a sharper one. Finally the back is undercut. The material is quartz or pyrex. They have used both. They have also waxed two plates together to give a black background (the wax) so as to observe the progress of the etching process.

A "modified Pierce gun" for the ionizer is shown in Fig. 59. The electrodes are assembled on glass tubes over metal rods with insulating spacers in the manner of many mass spectrometer sources. There are two water-cooled copper blocks which support the filament. They haven't decided whether the filament will be above or below the atomic beam in the cyclotron. Ionization takes place over a 2 cm long region. The source is supported by four rods. They think they may need

[43] J. N. Shive (Bell Laboratories) Properties, Physics, and Design of Semiconductor Devices (D. van Nostrand, 1959).

Fig. 59. General mechanical arrangement of the ionizer. The glass tube is an insulating water carrier. It is connected to the copper tubes by kovar seals. The unit is placed with the cyclotron field (B) parallel to the mounting rods shown. The cathode is 2 cm long, 6 mm wide and 2 mm thick maximum. It is shaped to give a "Pierce" beam (ref. 25). The cathode and adjacent electrode are at -400 V. The next electrode, also shaped, is 2 mm away and at 0 V. The plates beyond the atomic beam have slots 16 mm wide. The first is about 3 cm from the second shaped plate and is at 0 V. The next is 5 mm away and is operated at -100 V. The electron collector is at 0 V and is 1 cm beyond the -100 V plate. The minimum thickness of the electron beam is about 7 mm, about the same as the atomic beam diameter. The electrodes are of molybdenum. They believe they can operate in or out of the magnetic field (of the cyclotron) by adjusting the distance and shape of the electrodes and perhaps adding some. Extraction may be to the left or right. Details are not yet available, but the extraction electrodes will probably be from -1000 to -2000 V.

to add electrodes to shape the electron beam.
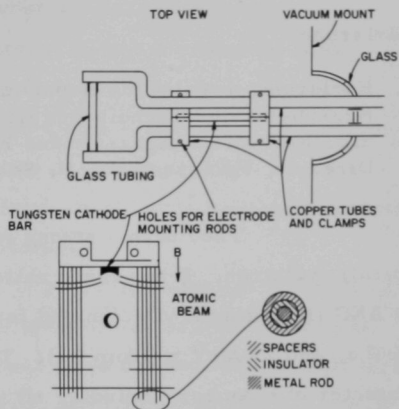
With this arrangement, the atomic beam is brought in at an angle to the median plane to miss the extractor (main cyclotron extractor) and also off center so the ions will be drawn into the center region of the cyclotron, that is in Fig. 59., ions were extracted to the left. Again it is necessary to compromise between the ionization cross section and the space charge limitation of electron current with voltage. Since the cross section is proportional to $(\ln 3V)/V$, and the electron current, to $V^{3/2}$, we have that the product of $I \cdot \sigma_H$ is proportional to $V^{1/2} \ln 3V$. This is for the high voltage tail that is somewhat above the maximum cross section or for V above about 100 eV. Of course, in some cases, one must consider the greater distance necessary for higher voltages so the $1/d^2$ factor comes in.

They have used a similar filament (on unpolarized protons) about a full week (168 hrs). This was a wire, not a ribbon. It just burns out. They expect to try this system in the small (model) magnet about the end of February 1965. The ion source will be in a field of 7−8 kG. They expect to cool with liquid nitrogen in the model and will at first try in the cyclotron without liquid nitrogen.

7. Karlsruhe, Institut für Experimentelle ·
   Kernphysik der Technischen Hochschule
   u.d. Kernforschungszentrums Karlsruhe
   Director, Professor Dr. H. Schopper

     They have a strong focusing (Thomas type, sector, not spiral) cyclotron. It has three valleys and three hills. It is the first built by AEG (Frankfurt). Designated for $m/e = 2$, it will give 50 MeV d, 100 MeV α, and 25 MeV p (from H_2). The diameter of pole tips is 2.25 m, diameter of chamber (including rf) is 5 m. There are three V's (instead of only one or two dees). They have had an internal beam of about 200 μA for about a year, and an external beam of about 10 μA (meeting the specified value during acceptance tests) for about three weeks (as of date of visit). The reason for the low extracted beam is that no more than about 14 μA internal beam can be used for extraction or internal parts of the machine will heat up. The extraction efficiency is thus about $70-80\%$. There is a tungsten wire channel which is heated by the remaining 30% of the beam. The maximum orbit has a radius of 107 cm. The orbit is contracted for extraction. The gap in the V at extraction radius is 4 cm. The rf is fed through a hole (axial) in the upper pole and the normal ion source is fed through an axial hole in the lower pole. So far as we remember for unpolarized particles, they introduce the whole ion source through this hole. The polarized particles might be ionized outside and introduced through the axial hole (see Birmingham). The three V's are fed in phase. With three accelerating regions, there is a much higher energy gain per turn, about 240 keV/turn, so the orbits are well separated and the energy spread can be kept low, possibly as low as about 50 keV at 50 MeV. (So they might be able to compete with a Tandem in precision.)

Dr. Weddingen expects to produce polarized protons by a-p scattering. They were going to use internal target but because of the small amount of room available (4 cm), they will start with an external system. With 200μA internal beam, they would expect about 10^5 polarized particles/sec. The polarization should be greater than 90%. For comparison they quoted as typical current from the linac in Minneapolis about 10^6 particles/sec with about 50% polarization.

Ludwig Friedrich (with the help of Dr. Brückman) is building a polarized deuteron source. They will test with an 800 kV Greinacher (this is apparently the historically correct name for the voltage multiplying rectifier system usually associated with Cockcroft and Walton[44]). If the system is operating, they will go to the cyclotron. There are, of course, plans to use adiabatic passage transitions.[4]

They use Heraeus pumps. The dissociator region is pumped by a 2000 L/sec oil booster pump (T2000 Heraeus). There are two 2000 L/sec oil diffusion pumps, one to be used in the transition region near the 6 pole at the other end of the transition region. A third pump can be installed under the 6-pole magnet. Initially they will try the system without the pump under the lens. All pumps have water-cooled baffles. We do not have information as to the pumping for the ionizer but there will probably be a Vac Ion pump.

There is probably about 1.8 m from the third (or second if only two are used) transition to the ionizer for the tests. (As at Saclay, use of three transitions is possible with the third used for plus or minus.) Only the ionizer is at HV. They hope for about 1−2 cm diameter beam all the way to the ionizer or at least at the ionizer. They can change the pole tip shape (of the 6 pole) easily. The ionizer must be a 28×28×40 cm box. The 6 pole (Fig. 60) is similar in dimension to that of Thirion. The precision of the final assembly (they have coded, i.e., non-interchangeable

[44]See, for example, R. P. Featherstone in, "Methods of Experimental Physics, Vol. 2 Bleuler and Haxby, editors,   (Academic Press, New York, 1964) p. 198.
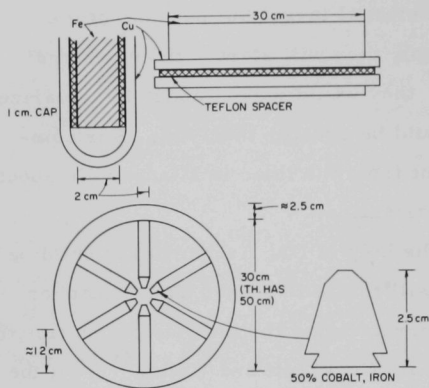
Fig. 60. Design of the six-pole. Note that the ring dimension of 2.5 cm is about the same as Thirion's. However, the cores are only 2 cm, that is, thinner than Thirion uses. The gap is "tapered" similar to the magnet of Thirion.

cores) is about 0.004 in. Coils are of nine turns and will carry up to 400 A. (Thirion uses 18 t and 80 A.) The conductor is hollow square copper, 7 mm outside and 3 mm inside. There are Teflon spacers at the core ends. They hope for a vacuum of 10^{-5} to 10^{-6}. The vacuum system is of aluminum. The ionizer is of stainless steel situated on insulators some of which are made by Rosenthal Isolatoren Selb/Bayern, others by Stemag/Holenbrünn (Obfr.) They are guaranteed for 120 kV for a 76.0 cm long unit.

They will use them at about 300 kV under air NTP. The accelerating tube and the vacuum tube for the neutral beam is made from ceramic insulators 60 cm long. They will use $3\frac{1}{2}$ of the insulators. They will assemble the insulators with rubber O-rings in retainer rings, 25 cm I.D. Under test they had a pressure of 3×10^{-6} Torr with a 10-in. pump (directly, no long lines or large system), so the insulators are vacuum tight.[*]

The source will use about 25 kW (with the ionizer which is at HV). The atomic beam will be horizontal at 3.2 m above the floor. The ions will be extracted perpendicular to the beam, also horizontal.

Brückmann. They have not yet decided whether to use a strong or weak field ionizer. They may try both. They will probably use a very simple design or Clausnitzer's design (Minnesota) to start with, as an introduction to the area of study. For the cyclotron they will design a special ionizer.

[*] Later information. They now have 3×10^{-7} at the same point.

The dissociator will not be particularly the Thirion design. They just made it the way one would if one had read the literature. They expect to use up to 1 kW (they have a 1 kW self-excited oscillator). Coupling to the discharge will be capacitative and the tube will be the U type. They expect a throughput of about 1000 L/sec at 10^{-3}, that is, about 15 cc STP/sec. They do not expect to use a Laval nozzle. At present, they plan to use a Heil ionizer in a weak field.

Some experiments under way in this laboratory at Karlsruhe. Dr. H. Brückmann and Dr. E. Hase are working on a neutron spectrometer combined with time-of-flight measurements. They will work with polarized neutrons from the (d, n) reaction to measure the Schwinger scattering. For the cyclotron, the rf is 30 Mc and the particle pulse is less than $\frac{1}{2}$ ns wide but is at a 30 ns rate. They combined a TOF measurement with measurement of recoil protons in a scintillator (measured in a second scintillator). The overlap ambiguity is resolved by scintillator energy measurements. They make a two (three) dimensional plot of TOF vs the recoil proton energy and plot intensity in the third dimension.

They have designed a solenoid to rotate the neutron spin. The coils for the solenoids are made by BBC.[*] They will have coils of 9×9 mm sq Cu with a 4×4 mm hole. They will have eight layers, 116 turns and operate at about 400 A max. They can turn 100 MeV neutrons with two solenoids 1.2 m long (the coil is 114 c long). They have iron on the outside principally for shielding. The effect on the field inside is not very large. They have a number of 400 A power supplies, one 50 kW motor generator at 30 to 40 V so they seem to have designed a number of items to use the 400 A capability.

G. Schuler is measuring the circular polarization of γ rays from the Li^6(d, p, γ) reaction.

---

[*] Brown, Boveri, and Cie.

Schmidt is working on a polarized ^{3}He target using optical
pumping as at Rice[35] and has about 5% polarization. They hope for about
40%. There are difficulties with contamination by gases other than ^{4}He.
There are no plans at present for construction of a polarized proton target.

Mainz   December 14, 1964

8.   Max-Planck-Institut
     Institut für Chemie
     Head of group: Professor Dr. H. Wäffler
     Dr. H. P. Jochim and H. Schober
        (are building a polarized ion source)

They are installing a 1.4—1.5 MV Greinacher[44]
built by Müllen, Hamburg.   The ion beam is vertical and
goes through the floor. The unit is assembled with Rosenthal insulators.
There are four other columns. They have one for an oil hydraulic
system which supplies power (10 kW) at the HV end, one for steering
controls. (They control by electromagnets with plexiglass rods.) They
have a new unit for the polarized beam. They also have a switching
system so they can use a 0—600 kV Sames (Societe Annonyme Machines
Electrostatique) rotating disk unit to get to lower voltages as the
Greinacher won't stabilize below about 500 kV. The source is at high
voltage (all, not just the ionizer). They have an oil immersed voltage
divider in one of the columns and oil   cooling   in the other. They
feel that use of an oil hydraulic system of transmitting power gives less
vibration than with moving belts or shafts . The source is mechanically
isolated from the accelerator tube. Jochim has been on the job about a
year. He hopes to have the unit completed in about another half year.
They will use TV metering. The HV cage is about 2.5 m sq by about 1.8
m high. It sits on top of the columns.

Waffler and Dr. Ziegler are more involved with the
electron linac, as are Professor Dr. H. Ehrenberg, and Professor Dr.
Fricke. (The last two are from the Institut f. Kernphysik der Johannes
Gutenberg Universität, Mainz.) It is shared equally by the Max-Planck
Institut and the University. With the 320 MeV linac, they can get mono-
chromatic gammas (hope for 100 MeV ± 2%). The current rating is
75 μA average, 2 μs pulses at 100 pps. It is also good for positron
experiments or bremsstrahlung measurements. Shielding is 3 m con-
crete.

The polarized work started as an interim job before the
linac was decided upon. They planned it as a d source as the vacuum
wasn't good enough for protons. Waffler decided to copy the Basel work
along about 1960. After they had it built, they had low and unstable
current and low polarization (K. Mehl, Kaufmann, Averdung).

It was decided to build a new source. Jochim and H.
Schober are doing this and they will test it in the next few weeks. The
old source is still essentially complete. They have the new weak field
ionizer working. The new source has a higher pumping speed. The first
stage is a Roots pump, used to avoid varnishing troubles. It is a
Heraeus Model R 1600 with a rating of 1600 m^3/hr. The next chamber
(before the lens) is pumped with two 1000 L/sec oil boosters (Heraeus
Model DT 1000). The lens region is pumped with a 3000 L/sec diffus-
ion pump (Heraeus DI 3000). The ionizer compartment by two stages
(that is differential pumping) of Consolidated PDV 300's.

They have had oil and ion pumps together but on different
chambers with isolating channels. They can heat their ionizer. They
will use a double walled vacuum system with the inner wall heated. The

two chambers communicate only through the various small channels. The
old sources (Erlangen, Jochim and Fritsch) used a current conducting
chamber. The new one has heating "tapes," that is, bead insulated wires.
They got down to 10^{-8} in about eight hours.

The dissociator and magnet chamber is soft iron, copper
plated inside. The magnet is a 6 pole. The dissociator is inductively
coupled to the rf. They may use a multicapillary system or a single hole.
The multicapillary systems are made by Schott (formerly Jena) Mainz,
Mr. Jacobson, Jr. The capillaries are 0.12 mm I.D. 0.15−0.18 mm
O.D. and the outer case is about 8 mm O.D. The outer glass is G20
which is similar to Pyrex.

The 6 pole is tapered from 4 mm to 8 mm at middle and
then constant at 8 mm to the end (similar to Saclay q.v., p. 26). The
total length is 30 cm. It is a PM type using Hyperm Zero from Krupp.
This is supposed to be pure iron carefully annealed. Krupp claims that
they can get 10 kg at the tip (8 mm diameter)[*]. At Max-Planck-Institut
they measure the field with a small Hall probe from Siemens-Schuckert
in Erlangen. It is an InSb probe about 1.5×1.5 mm. (This is about the
size we are to get from Radio Frequency Laboratories.) The permanent
magnet material is Koerzit 500, Krupp Widia. Jochim talked of the pos-
sibility of using "Stengel" crystals or grown Ticonal (cf. Basel, p. 46).
They use the usual shape of tip, that is, three flat surfaces (cf. Karlsruhe,
p. 67, but not of 50% Co-Fe, the tips at Mainz are of soft iron as noted
above). The yoke is circular with slots for locating the core-tip assemblies
and holes for pumping.

Jochim has measured the output vs the pressure and this
information is in his thesis.[45] Dissociation was measured by MoO plates.
One can also measure the relative degree of dissociation by recombination
heat, but the absolute degree of dissociation is mucn more difficult to

---

[*]Later information, this has been essentially achieved.

[45]H. P. Jochim, Quelle Polarisierte Ionen und Nachweis der Polarisation von Deuteronen,
Dictoral thesis, Friederich-Alexander-University, Erlangen, Germany, 1962, unpublished.
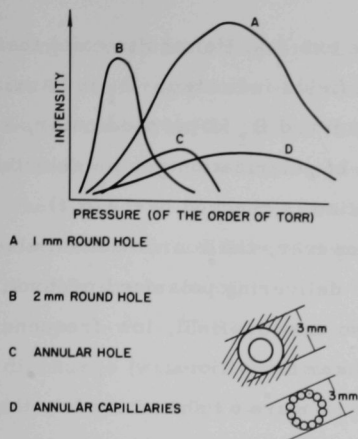
Fig. 61. Plot of the intensity from the dissociator vs the pressure for various apertures (after Fritsch, ref. 46).
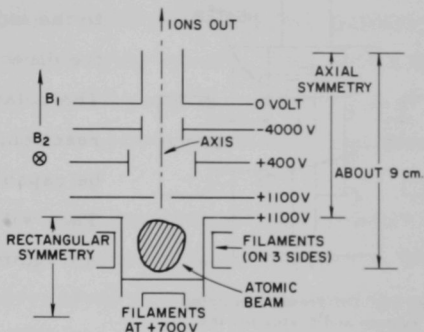
Fig. 62. Approximate layout of the ionizer. B_1 is used to produce longitudinal polarization and B_2, transverse, relative to the beam direction.

measure. G. Fritsch has made measurements with different types of apertures.[46] They think a single hole is as good as or better than a multicapillary because of increased recombination in the course of time. The intensity is approximately constant for a variation in hole size from 1 to 2 mm diameter. This is shown in Fig. 61 which is copied from Fritsch (ref. 46, p. 21, Fig. 9). Fritsch also finds no detectable difference between a 4 pole and a 6 pole. Jochim thinks small angle scattering is very important. One needs a good vacuum in the 6 pole.

The ionizer is a combination of cylinders and squares. In Fig. 62 the portion below the indicated line is square and there are filaments on three sides. The part above the line consists of cylinders and round holes. The "0 volts" is the source reference. This point is approximately at accelerator high voltage $(0-1.5$ MV). The whole ionizer (the reference 0 volts) may be up to plus 40 000 V from the accelerator input in order to obtain better extraction and to diminish the magnetic deflection

---

[46]G. Fritsch, Dictoral thesis (title unknown) Friederich-Alexander-University, Erlangen, Germany, to be published soon.
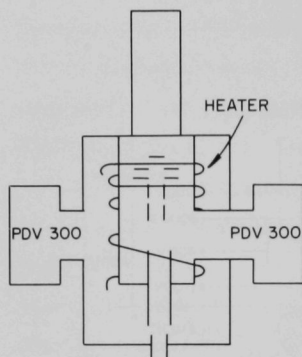
Fig. 63. Differential pumping system and heater for the ionizer.

caused by the external Helmholtz coils that establish the fields indicated. B_1 is parallel to the ion beam and B_2 is perpendicular, so the direction of polarization can be selected. The polarization is checked by the (d, t) reaction. However, the source should also be capable of delivering polarized protons. They will also use low-field, low-frequency Abragam-Winter transitions.

Figure 63 shows crudely the pumping arrangement and the heater.

Eindhoven   December 15-16, 1964

9. Technische Hogeschool te Eindhoven
    Professor Dr. O. J. Poppema, Drs. W. A. Bruil,
    Ir. J. A. v.d. Heide, Dr. G. J. Nijgh, Dr. B. J.
    Verhaar

They have an operating polarized ion source and expect to produce H^- by charge exchange of positive polarized hydrogen ions in an Al foil. They have performed this charge exchange with unpolarized particles with the remarkable efficiency of about 10% (P.J.M. Janssen[47]). This source is intended ultimately to be installed at the EN-Tamdem (12 MeV) of the University of Utrecht, Holland, which has been ordered and is expected to be operating by the end of 1966. Generally responsible is Professor Endt; in direct charge of the Tandem is Professor Hoogenboom. One interesting feature of their positive polarized ion source is that most

[47] P. J. M. Janssen, Inderzoekingen aan de omvorming van een bundel waterstofatomen tot negatieve waterstofionen. Master's thesis under Professor Dr. O. J. Poppema, Technische Hogeschool, Eindhoven, the Netherlands, unpublished, in Dutch, (1964).

components, including a 40 L/sec ion pump for differential pumping of
the ionizer region are mounted without separate housing on top of a
water-cooled baffle (about 70 cm diameter) of a 14 000 L/sec Balzers oil
diffusion pump (the baffle reduces the pumping speed to about 6000 L/sec).
The small Vac Ion pump inside the large oil pump has not been ruined but
since there is a differential pumping arrangement the ion pump probably
doesn't see much oil.

The hydrogen atoms are generated by a "conventional" rf
discharge (water cooled) dissociating "technically pure hydrogen." They
have used the inlet gas moist and dry (dried at liquid nitrogen temperature)
and got little difference in results. They are not sure of the relative con-
tributionto varnishing.

The
dissociator operates
at about 200 MHz
(about 50 W). With
this high (relatively)
frequency, one can
easily use ES coupling
(Fig. 64). They found
there was little effect
on the dissociation
whether the discharge
is water or air cooled.
They adjusted for a
"fine red" discharge.
It may be necessary to
start the discharge with

Fig. 64. General layout of the apparatus (after Janssen, ref. 47).

a tesla coil, probably because of low power. They have used $\frac{1}{4}$ to $\frac{1}{2}$ cc
ntp/sec of hydrogen (a function of the diameter and shape of the orifice)
and obtained a maximum beam intensity of 2×10^{16} H atoms/sec cm^2 at

a distance of about 5 cm beyond the 4 pole. The diameter of beam is "a few millimeters" measured with molybdenum oxide so "current" was about 10^{15} atoms/sec. This was for a 2 mm diameter orifice and 2.5 mm diameter diaphragm between orifice and 4 pole. The distance from orifice to diaphragm was 7 mm and from diaphragm to magnet was 30 mm. The pressure in the dissociator (oil manometer) is about 0.3 Torr.

With 4 mm diameter orifice and diaphragm, they got about the same flux so there was about four times the "current" because of the larger beam area. With 6 mm diameter openings, they had poorer results which they are reasonably sure were due to a lower degree of dissociation. They think that with an extra 2000 L/sec Hg differential pump 10^{16} atoms/sec might be obtained at exit of 4 pole (with a throughput of about 5 cc, ntp). They haven't done this.

They tried capillaries but feel the results are inconclusive. They spent time learning how to make them and finally built a drawing machine.

They use a Balzers vacuum needle valve for fine control of the gas flow. If they add water, it is through a needle valve as vapor. They use polyvinyl chloride tube with a support spiral. The discharge doesn't come back through the capillary that feeds gas in and out.

They have a 30 cm long 4 pole with 12 mm diameter apertures at about 12 000 G at the tips. They have 7 turns (per pole) of 8 mm diameter copper with a 5 −6 mm hole. This is run at 750 A. The coils are insulated with Araldite. The yoke is 30 cm O.D. and 1−2 cm thick. There are pumping holes. The whole unit is made of normal mild steel. The power input is about 8 kW (2 per pole). They intend to use Abragam-Winter transitions.

They had trouble with their atomic beam measurements. They felt that this was due to rf leakage to the ion gauge. They tried some shielding which didn't help so they shifted to a Penning gauge. This

is not affected as much but they still had trouble. They feel now that this was caused by depolarization inside the quadrupole magnet due to rf leakage. Addition of some steel sheet shielding (Fig. 64) restored the focusing effect of the quadrupole.

They have a low field ionizer, similar to that of Weiss[48] except that at Eindhoven they use cylindrical asymmetry instead of the flat geometry of Weiss (Fig. 65). The filament is a spiral about 2 cm diameter and 12 cm long, made of 0.2 mm diameter thoriated W wire (about 24 turns). The anode is about 1 cm diameter (also of spiral construction). With 3−4 A fil current, have a field of about 10 G, due to the action of the filament

Fig. 65. The ionizer, showing the axial and radial variation of potential (after Janssen, ref. 47).

solenoid. They use about 600 eV electrons and since there is about 100 V drop along the filament, there is a tapered field which should give better ion extraction. The electron current is about 500 mA. (Basically radial but note possible effect of B and dV/dz.) The atomic beam is only a few mm in diameter. Electrons of 600 V are about the optimum for this arrangement. They calculated that the efficiency should be about 0.2% and they measured about 0.4%. This was estimated from yields with the magnet on and off. The later models use a cylindrical anode of "cylindrical spot-welded framework of tungsten wire" instead of the spiral wound anode.

The background pressure in the ionizer is between 10^{-6} and 10^{-7} Torr. They have had 140 nA in the ionizer but the background was

[48] R. Weiss, Rev. Sci. Instr. _32_, 397 (1961).

ten times the signal. That is, there is a 10% change of current when the
4 pole is switched on or off. From ram tube and manometer measure-
ments, they estimated that there are about 10^{15} particles/sec in the beam
at the ionizer.

To effect the change from polarized H^+ to H^-, they have used 20 μg/ cm^2 (and down to 10 μg/cm^2) aluminum foil and have obtained up to about 10% efficiency in the charge exchange at about -10 kV.
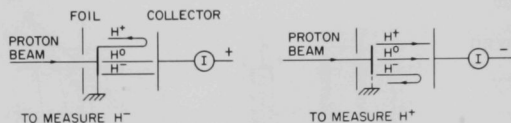
Fig. 66. Arrangement for charge exchange measure-
ments (after Janssen, ref. 47).

There is the question of the effect of higher voltages. They may try it but
the setup they used is now (December 1964) dismantled. They used
electrostatic suppression of the electrons (Fig. 66). They claim that
they do discriminate against secondary electrons because of the energy
difference. From the graphs of the efficiency vs voltage (Fig. 67), one
would expect that a higher voltage would give a higher efficiency. At
Eindhoven, Janssen[47] measured as a function of incident energy, as did
Fogel[49] while Phillips[50] measures for emergent energy. Fogel has about
7% conversion at 15 keV while Phillips has about 5% at 5 keV. Phillips
used a magnet separator to identify the emergent ions so there is no
question of secondary electrons in that case.

The aluminum foils are made in the normal way, by
evaporation. They take ordinary kitchen aluminum foil, place it in a
tungsten boat, spiral or gutter, and evaporate onto a glass plate that has
been coated with TIPOL film. The ambient pressure was not indicated.
They use the dip and lift technique for transferring to the support plate.
The foil is placed over a hole about 5 mm diameter. They do not use

[49] I. M. Fogel, Soviet Physics 1, 546 (1955).

[50] J. A. Phillips, Phys. Rev. 97, 404 (1955).

MEASURED CURRENT AS % OF INCIDENT PROTON CURRENT PLOTTED AGAINST INCIDENT ENERGY

ALUMINUM FOIL, UNCLEANED, CURVES FROM JANSSEN
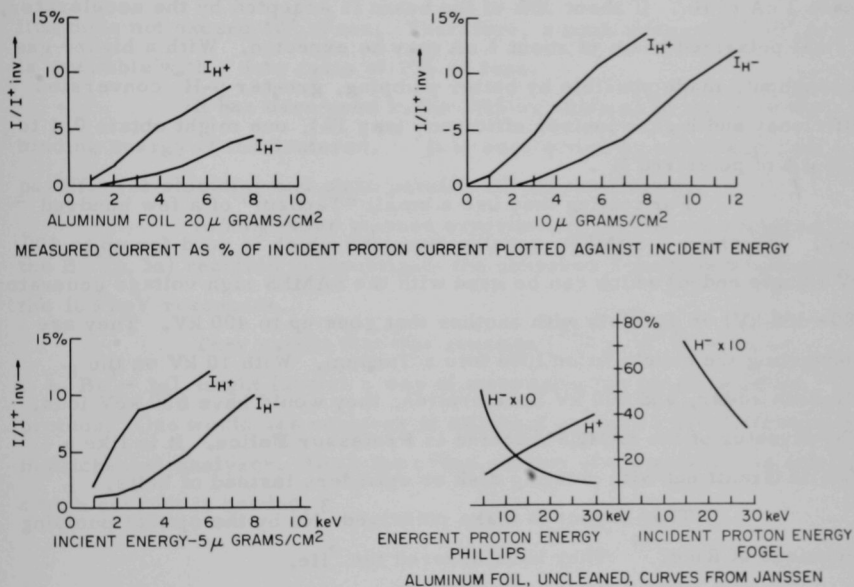
Fig. 67. Charge exchange efficiency curves (after Janssen, ref. 47).

a support mesh. They suggested that one could use optical or alpha ray measurements of the thickness. The desired density is such that the optical transmission is about 10%.

They are not certain of the effect of surface coats (e.g., pump oil on the aluminum foil). They also had no comment on the effect of the foil adder on the emittance of the beam. They would like to measure this but need a student to do it.

General Remarks

Estimate of the performance. They have an atomic beam of about 10^{15}. (Actually they have had as high as 4×10^{15}.) If one assumes an efficiency of 0.05% for the ionizer, one would have about 80 nA of protons with a polarization of about 30%. This can be increased by use of rf transitions. With a "reasonable" efficiency for the adder, there is at least 3 nA of H$^-$. If about 30% of the beam is accepted by the accelerator, a final polarized beam of about 1 nA may be expected. With a higher gas throughput, made possible by better pumping, greater p-H$^-$ conversion efficiency and higher ionizer efficiency (say 1%), one might obtain 0.1 to 1.0 μA of polarized H$^-$.

For testing they use a small "Tandem" of a few hundred keV. They have a SAMES[*] acceleration tube which is good for up to 400 kV (single ended) which can be used with the SAMES high voltage generator (80 − 300 kV) or possibly with another that goes up to 400 kV. They are converting the acceleration tube into a Tandem. With 10 kV on the electron adder, and 300 kV acceleration, they would have 620 keV ions. The inventor of the SAMES machine is Professor Felice. It is like a Van de Graaff but with rotating disk or cylinders instead of belts.

They expect to make polarized ^{3}He by the optical pumping technique of Rice.[35] They have ordered the ^{3}He.

They have a small neutron generator, a (d, t) unit sealed off. It is purchased from Philips in Eindhoven. This was developed by Dr. O. Reifenschweiler.[51] There is a 50% D, 50% T mixture in the tube, a Penning discharge is set up and the particles are accelerated by 125 kV. The metal target (silver with a few microns of titanium) is self loading

---

[*]Societe Anonyme de Machines Electro-Statiques, Grenoble, France.

[51]O. Reifenschweiler, Philips Res. Reports 16, 401 (1961); O. Reifenschweiler, Nucleonics 18, No. 12, 69 (December 1960).

with D and T (due to bombardment) and then is the site of the reactions. The system costs between \$k 7 and \$k 10. There is a reserve of gas in Ti which can be heated to recharge the unit. At 10^6 n/sec μA, the typical operating current is 100 μA (with 125 μA as the maximum), the yield is 10^8 n/sec. The operating life is supposed to be 400 hrs minimum under the above ratings. The neutron generator may be pulsed in such a way that the average flux does not exceed 10^8 n/sec and the momentary flux does not exceed 10^9 n/sec. Therefore, a peak intensity of 10^9 n/sec is available with a duty cycle of 10% or less.

It has been used in the THS by students to measure the binding energy of the deuteron.[52] It is surrounded by boron enriched paraffin for shielding and plain paraffin for thermalization.

Among other planned experiments for the near future is the B^{11}(p, 3a) reaction to investigate the observed 3 particle breakup at the 163 keV resonance.

They expect that this reaction [^{11}B(p, γ)^{12}C $\rightarrow$ 3a or a + ^{8}Be^3 $\rightarrow$ 3a] might furnish a way of measuring the polarization of protons. One would use counters at different angles as usual, feeding a multichannel analyzer. Since the cross section of the reaction is small, a high current is needed.

---

[52] E. Ortiz, Am. J. Phys. 29, 684 (1961).

December 18-19, 1964

10. Erlangen, Germany
    Physikalisches Institute der Universität
    Director: Professor Dr. R. Fleischmann
    Senior of all polarized source development:
        Dr. G. Clausnitzer
    Tandem source (dissociation, 6 pole):
        E. Salzbaum and W. Durr
    Hf transitions: H. Wilsch
    Charge exchange: J. Witte
    Ionizer for Tandem source: G. Graw
        and H. Hofmann
    d(d,p)T reaction (using older source for
        p and d which was constructed by Dr.
        Fritsch and Dr. Jochim): D. Fick
    Small 8 pole p source for a high potential
        electrode: J. Henning and A. Schatz
    Polarized ^{3}He by optical pumping:[35]
        W. Klinger

        Historically, the first polarized hydrogen source incor-

porating most parts of the present "conventional" scheme was built in

this laboratory.[53]   Besides the oldest source now in operation here,[54]

there are several other operating test sources and a negative polarized

ion source which is almost completed and is to be used with the new EN-

Tandem (12 MeV) accelerator which is expected to start operating during

1965.

        The old source[54] (built around 1959) is used with a 150

keV Cockcroft-Walton[*] with the target at high voltage. The current to the

target was measured with a transistorized "Ampere Meter." They had

2.5×10^{-8} A of polarized d on the target. The polarization of the d was

measured with the usual ^{3}H(d,n)^{4}He reaction and the emitted neutrons

------

[*]Commercially built by Zeiss.

[53]G. Clausnitzer, R. Fleischmann, and H. Schopper, Zeitschr. f. Physik 144, 336 (1956);
G. Clausnitzer, Zeitschf. f. Physik 153, 609 (1959).

[54]R. Fleischmann, Helv. Phys. Acta, Suppl. VI, 26 (1961); H. H. P. Jochim, dissertation
1962, Universitat Erlangen (unpublished).

were observed at ground potential. They had a value of P_{33} of about -0.27 (the theoretical maximum is -0.33). There was about eight times as much current from the ionizer as they got on the target. The source can also be used for protons.

Fick is now using this apparatus to study the $d(d, p)^3H$ reaction with photographic plates for detection of the protons.

In the weak field ionizer (built by Fink) they have about 2×10^{-8} Torr residual gas pressure without the accelerator tube. The ionizer is shielded inside the normal vacuum by a special housing which can be baked to $500°C$ by a current of 500 A going through its walls. With the accelerator tube, the pressure is about 5×10^{-7} Torr. They can use a small mass spectrometer to analyze the beam. The atomic beam flux through the ionizer is about 4×10^{14} atoms/sec. The ionizer (Fig. 68)

Fig. 68. Cross section of the weak field ionizer. The anode A is at +1600 V and the cathode K is at +1400 V. The ion repellor R is at anode potential while the electron beam forming plates BF are at cathode potential. The extractor E is at +700 V and the following lens element L is adjusted as needed. All voltages with respect to "ground." The nickel cathode is "Pierce shaped" (ref. 25) and is mounted on nickel rods. The cathodes are about 1.5 mm wide and the anode-cathode spacing is about 2 mm.
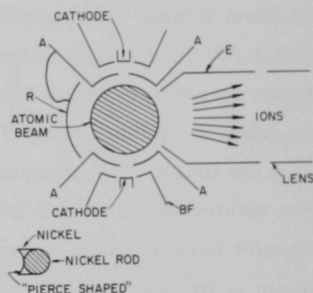
efficiency is about 2×10^{-3}. The overall loss is 8:1; that is, 1/8 of the ions which are extracted get to the target. They get a 9 cm wide ribbon with an angular divergence of $6°$ perpendicular to the 9 cm dimension. This must be focused down to a 1.5×3 cm cross section. They get 50% of the ribbon. Of this, 50% goes to the accelerating plates and 50% of the remainder goes to the focusing electrodes. The target is 3 cm^2 at an angle of $45°$ to the beam. They have tried various focusing methods to reduce the 9 cm $\times 6°$ beam to the desired cross section, such as electrostatic quadrupoles and slit (not aperture) lenses formed with curved

instead of straight edges. (Fig. 69). They feel that one can get a better focus with ES Q poles. For acceleration they use a spherical lens system.
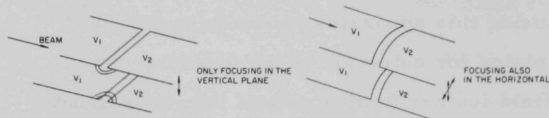
Fig. 69. Two dimensional focusing lenses. Because of the curvature, the right unit focuses in a plane parallel to the electrodes as well as in the perpendicular plane.

The ionizer has two electron guns with "Pierce" type anodes.[25] They form the cathodes from 0.05 mm thick nickel and have them coated with oxide by Siemens Halske. The coat is about 0.04 mm thick. Nickel rods are put at the ends. The anode cathode spacing is about 2 mm. The operating conditions are, anode cathode voltage about 200 V, electron current, 400 mA (for both filaments). The atomic beam entrance is about 7 mm diameter. The total length of the cathodes is about 10 cm with about 9 cm active length (and so the ionizing region is 9 cm long). The advantage of this construction is supposed to be that the volume of the atomic beam is about equal to that of the ionizer so one doesn't have so much background problem. (Therefore, if the electron beam is immersed in the atomic beam as is probably with our source, the background should be even lower—DCH 2/25/65.) The emittance of such a source is too large to be accepted completely by the Tandem accelerator. To obtain an idea about the beam shape they normally use a piece of a television screen, but it has only a short lifetime under the ion bombardment.

The signal to noise ratio when the 6 pole is switched on and off is about 3.5:1 when measured with the compression tube-ion gauge combination, and when measured on a ^{3}H target with d (on Jochim's machine)[54] there is little difference.

They have the cathode at only about 800°C to avoid thermal dissociation of hydrogen molecules in the residual gas. They define a critical value between 1000°C and 2000°C.

With Jochim's source, switching the 6 pole on and off doesn't affect the pressure in the ionizer as the beam is trapped in a volume beyond the ionizer. Fritsch did a thesis (to be published) on the 4 and 6 pole (which gave similar results). A comparison between the 6 pole and the 4 pole is approximately as shown in Fig. 70. The curves were partially calculated (from impact tube-ion gauge measurements) and partially measured from molybdenum oxide plates. The 6% $m_J = -\frac{1}{2}$ contribution in the center of the 6 pole deflection pattern is due to the axial beam and an axial stop probably improves the polarization but decreases the intensity about 25%.

Fig. 70. Particle distribution for 6-pole and 4-pole lens. The center portion of the 6-pole distribution represents $m_J = +\frac{1}{2}$ mixed with 6% of $m_J = -\frac{1}{2}$. The maximum is about 5×10^{14} atoms/sec, 87% polarized and 13% unpolarized. The slight dip in the peak is due to an asymmetry of the 6 pole. The lower peaks to the right and left are due to $m_J = -\frac{1}{2}$. The peak for the 4 pole represents a pressure of about 10^{-6} Torr which corresponds to about 10^{16} particles/cm² sec, approximately 100% polarized ($m_J = +\frac{1}{2}$).
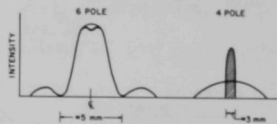
Fritsch[55] in his thesis concludes that a 6 pole is a little better in intensity than a 4 pole even with tapered fields. Note the above asymmetry in the 6 pole amounts to a superimposed dipole. A comparison of the fields and gradients is given in Fig. 71.

The new Tandem source is being constructed by Salzborn and Dürr. It is shown in Fig. 72. The vacuum housing is a 20 mm thick stainless steel rectangular box about 50 cm square and about 1.3 m long. It is divided into three chambers. Access is through 10-in. ports with

---

[55] Diplom-thesis of Fritsch, 1959 (unpublished).
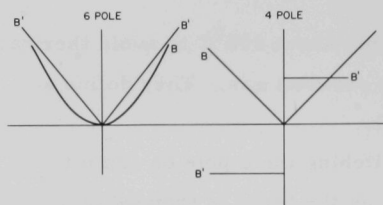
Fig. 71. Magnetic field and gradient distribution for 6 pole and 4 pole.

the appropriate flange detail (bolt holes and gasket grooves if desired) machined into the flat plate.

They are using air-cooled and water-cooled discharge tubes with water in the rf field (Fig. 73). They investigated a Teflon
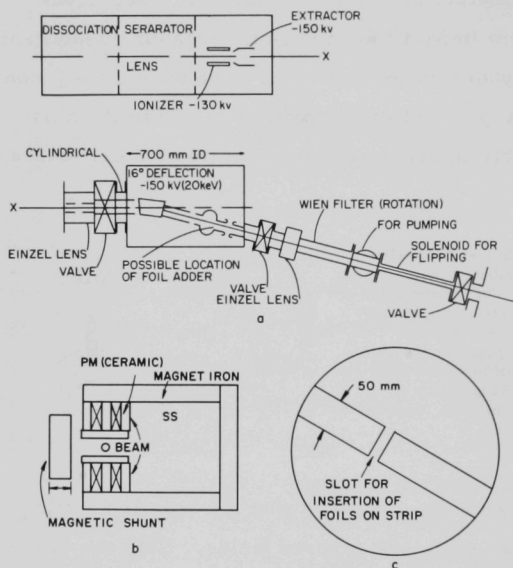
Fig. 72. (a) Outline of the new Tandem source including the deflection system, charge exchange, and direction controls. This arrangement is tentative. The 16° magnet is at -150 kV but the ions have only 20 keV energy as the ionizer is at -130 kV. (b) Deflecting magnet design. Note that the ceramic magnets are sealed (at atmospheric pressure) with stainless steel sides welded to the pole tips and yoke. (c) Arrangement of the charge exchange system.

capillary system that is a drilled block of Teflon, but the degree of dissociation was less than 10%. The best degree of dissociation was achieved with a hole in ordinary pyrex. The flux density of polarized hydrogen atoms is measured with a compression
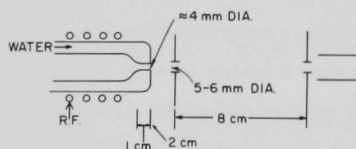
Fig. 73. Sketch of the dissociator for the new source.

tube and ion gauge. They now have $(1-2) \times 10^{16}$ atoms/sec cm^2 over approximately a 7 mm diameter. This corresponds to a pressure of about 10^{-6} Torr of polarized atoms at the ionizer. With the ionizer of the old source, they get 0.45 µA of protons in the ribbon. With the new ionizer they hope to get 1 µA with better emittance. They have little hope of getting more neutral beam. The 6 pole has a cross section as indicated in Fig. 74, and in

Fig. 74. Cross section of the 6 pole for the new Tandem accelerator.

15 cm long. The tips are a 50% cobalt alloy.

The strong field ionizer to be used with the Tandem source is being built by Graw [Fig. 75(a)]. Note the double cone arrangement. They want to have space charge extraction (or expulsion) of the ions.[25,48] The potential distributions are indicated in Figs. 75(b) and (c). Because of the shape of the electron beam, there is a potential depression between the electron beam and the walls. When the beam diameter is constant and the distance to the walls becomes greater, the potential depression becomes greater also. This means that the potential varies along the ionizer, roughly as shown and the positive ions go to the point of lowest (most negative charge) potential. Note that this means that, (a) the ions formed to the left of the minimum diameter of the shell will probably be ejected to the left and thus lost (and also probably bombard the cathode) and (b) the potential variation will have some effect on the velocity and current in the electron beam.

Sintered W cathodes should be available from Siemens-Halske and also possibly from Valvo. They need careful handling. [Siemens-Halske, Munich, Dr. Veith; Valvo, 2 Hamburg-Kokstedt 1, Stresemannallee 101 (letter to Graw from Dr. te Gude, 27 May 1964).]
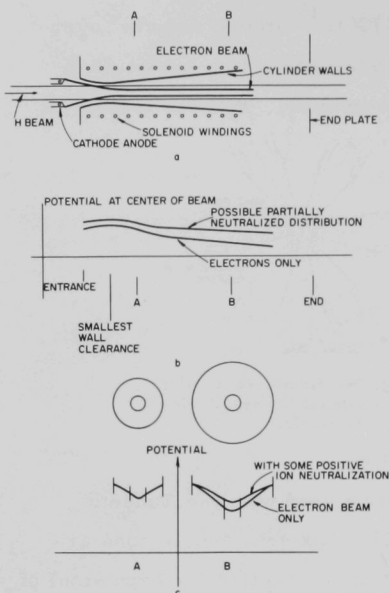
Fig. 75. (a) Principle of the strong field ionizer. The double cone arrangement is expected to aid in extraction of the ions. The cathode is indirectly heated, oxide coated. A grid may be used over the aperture in the anode. (b) Estimated variation of potential along the axis of the ionizer. A guess as to the distribution for partial space charge neutralization by the positive ions is also shown. (c) Estimated potential variation in the ionizer at the two locations indicated. The relative diameters of electron beam and wall are shown.

Porous ("Poröses") tungsten can be attached by Mo-Ni soldering to a U-shaped Mo sheet to form a flat cylinder in which the heating coil can be introduced. They are 5×20 mm and give over 1 A/cm^2. It is porous W loaded with oxides — sometimes called a dispenser cathode (Vorratskathoden). The ones from Valvo cost about 1600 DM for about 15 cathodes.

J. Witte is working on the problems of charge exchange and the ion beam handling devices between the positive ion source and the introduction of negative ions into the Tandem. The ionizer is at -130 kV and the extraction cone is at -150 kV so they have about 20 keV net extraction. This is better than the 2 keV they previously used. There may be an einzel lens in the space shown. The reference voltage is -150 kV and it is necessary to have a movable cylinder which can be projected through the valve when it is open so that the einzel lens sees the proper potential and also there is no unwanted lens action due to the presence of ground. Witte's work is to the right of the valve. The deflection system (PM) separates atoms from the molecular ions. At 20 keV, need 330 G for p and 470 G for d. Radius is 620 mm. Field change by shunt. Note that their Wien is after

the charge exchange so they must use a fair energy or else decelerate.
They have several alternate suggestions if the Wien proves unworkable.
These, according to Witte, are for example, another magnet which would
bend the H^- orbit back by 16.1^o thus rotating the spin further to a total
of 90° relative to the beam direction.[*] The D^- orbit should be bent back
by 49.8^o. Or, two 52.7^o magnets, one inside the chamber (instead of
the 16° magnet) and the other outside would be advisable for deuterium
(the D^- beam would leave the chamber through a side wall opening.
Charge exchange would take place outside the chamber. Or, for protons
only, a single 50.2^o deflection giving 90° ritation of the relative spin.

The foil unit is separate so that it can be placed at the
appropriate voltage, e.g., -140 kV which would give 10 keV for the charge
exchange. Since the most efficient energy is not yet known, this is
adjustable. The box shown is 700 mm (inside dimensions) long, 480 mm
wide, and 265 mm high. The wall is about 15 mm thick of stainless steel.
The charge exchange foils are placed on a strip which can be moved to
expose a new foil. Construction of the magnet is outlined in Fig. 72(b)
and the detail of the foil holder in Fig. 72(c). (NOTE: Many of the units
themselves are at high negative voltages and must be appropriately insulated
and the ion beam must be shielded from ground.) The ceramic magnets
are sealed (at atmospheric pressure) with stainless steel sides welded to
the pole tips and yoke as indicated. This is because the ceramic is not
good at high vacuum, probably too porous. The large box ($700 \times 480 \times 265$
mm) is designed for other magnets and systems as desired. It will be
pumped by a 400 L/sec Ultek pump from below. The Wien and the Solenoid
are both 340 mm long. The pumping space is 240 mm with a 100 L/sec
ion pump. At present, the solenoid is a weak one, about 110 turns, with
an inside diameter of 30 mm. They quoted figures for 20 keV protons.

---

[*]Later information is that this is being tried in July, 1965.

One needs 350 G (ca. 85 A) over about 32 cm to precess 90°. For 150 keV

then one needs about 980 G (ca. 225 A). The coil is 4 mm O.D., 3 mm

I.D. OFHC Cu with plastic sleeving as insulation. The winding is not in

the vacuum. Iron shielding of the solenoid is probably only effective in

linearizing the field (Fig. 76) but the HL integral should be greater. Need

to consider the focusing of the solenoid (end effect).
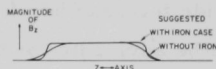
Fig. 76. Estimated effect of
iron shielding on the distri-
bution of the magnetic field
in a shielded solenoid.

On charge exchange (using carbon foils). They haven't done this yet but the Technische Hochschule München evaporates carbon from two carbons in con-

tact (i.e., merely resistive heating, not an arc). This is a Diplomarbeit

of Marx. An evaporating unit is available from Balzers (Aufdampfanlage).

It is shown in their catalogue on High Vacuum Apparatus, Mikro BA-3,

Wechsel Flange BA3B für Kohleverdampfung. It lists at about DM 625.

Marx didn't know how thick the foils were. He quoted 2 μg/cm^2 but now

doubts the value. They will measure the thickness by a Tolanski microscope

(an interferometer). The foil will be measured on the glass (can't

measure on the frame). The foil thickness will be estimated by the

absorption of light (calibrated by means of the Tolanski). This will be an

easier job. The glass was wiped with nylon stocking before evaporation,

since the stockings are impregnated with some substance that seems to be

good for release of the deposited foil.

Schatz and Henning are constructing a small isolatable

(300 kV) polarized proton source. This will use only air cooling. They

use a magnetically coupled discharge in the dissociator, at about 500 W.

They have an 8 pole permanent magnet lens with ion pumping elements

between the poles. There will be no rf transitions. They will use a weak

field ionizer similar to that of Weiss.[48] The atomic beam and the ion

beam are parallel. There will be a small space charge (electron) depres-

sion at the entrance of the atomic beam and a much greater one at the

output end. Thus, they can extract axially and hope for a good quality beam. They are doing "ray tracing" to study the characteristics of the beam in the 8 pole. They use a small hole which can be moved to give different "rays." They have successful exposures on MoO plates in 10 min or less. The ionizer should be ready this year (1965).

There is also an apparatus for various discharge testing purposes at Erlangen using a conventional 2-pole magnet as separator (Rabi-type). Among other things discharge properties have been investigated with this apparatus[56] the hydrogen discharge changed its color from red to pale when it was cooled with liquid nitrogen surrounding the glass container but this color change did not occur if the glass container was replaced by Teflon.

Wilsch on 4 pole, compression tubes and ZnO-crystal detector. Source for testing purposes. Uses about 1 kW (2 kV at $\frac{1}{2}$ A) and around 20 Mc for the dissociator, E coupled to tube, as the brass holder is too small to use inductive coupling. He prefers a single channel 2 mm diameter by 3 mm long to the multicapillary. He has the old 4 pole (from the original source[53]) with the coil reworked so that now it is 5 turns/pole at 800 A, water cooled (tubing). The poles are 12 cm long and the gap (diametrical) is 5 mm. The poles are not tapered. The field is 0 on the axis and 6000 G at the tip (so, 24 kG/cm). The "focus" is 6 cm (Fig. 77) behind the magnet. In addition to the compression tube

Fig. 77. Arrangement for Wilsch's measurements. The two pumping ports lead to two 500 L/sec oil diffusion pumps with the heaters operated at 1250 W instead of 800 W. There are also water-cooled baffles. (b) shows an alternative arrangement using a compression tube and pressure gauge.
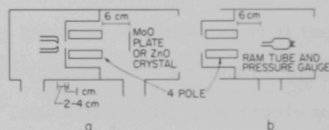
shown as an alternate, a ZnO crystal detector was used. Comparison of the pressure tube readings and the crystal indications show some differences. One assumes that the ZnO signal should be linear with intensity

---

[56]Diplom-thesis of Lindner (unpublished).
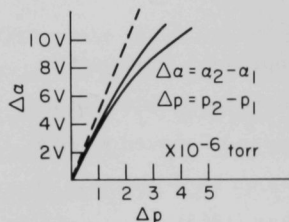
Fig. 78. Calibration of the ZnO detector. The upper, dashed curve is the expected variation of Δa with Δp. The lower is the experimental one and the middle is the assumed "true" curve. These experiments were repeated five times and the same curves resulted.

of atom beam (Fig. 78). With the 4 pole off, we have readings p_1 and a_1 for the compression tube and the crystal respectively. With the 4 pole on, p_2 and a_2 where the sub twos are larger than the sub ones. The a represent the change of conductivity of the crystal.

Operation of ZnO detector.[57] A needle of ZnO single crystal, with a diameter of about 0.1 mm and a length of about 4 mm has Au electrodes
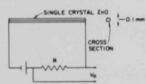
Fig. 79. Circuit for ZnO detector. V_0 is approximately proportional to the crystal conductivity if $R \ll R_x$ where R_x is the crystal resistance.

evaporated on the ends. The circuit is as shown in Fig. 79. The conductivity of the crystal σ is made up of the volume and surface conductivities $\sigma = \sigma_{vol} + \sigma_{sur}$. The conductivity is the reciprocal of the resistance. The volume conductivity is a constant for a given crystal. The surface conductivity depends on the cleanness of the surface. It is greater with H on the surface (not with H_2). Only a length of 1 mm is exposed to the beam. The conductivity is measured. The crystal is heated after each measurement by discharging a capacitor through it. About 100 V dc is needed but I don't have the value for the capacitor.[*] The crystal glows momentarily and it is possible to destroy it. The measurement of significance is the slope of the rise of conductivity (Fig. 80). This is the a and is obtained by electronic differentiation. The system is cycled as indicated on the curve. The cycle time is approximately 15 sec associated with the heating and regeneration of the crystal. Some crystals will work at room

---

[*] Later information. The value is from 10 to 50 µF.

[57] Diplom-thesis of Haberecker, under supervision of Prof. Mollwo, Universitat Erlangen.

temperature. All
they have tried work
at liquid nitrogen
temperature. One
uses the one in 100

Fig. 80. Response curve for ZnO detector. σ_v is the volume conductivity and σ_s is the surface conductivity. The initial value of σ_s is σ_{s0}.

that will operate at RT. The effect would be greater at lower temperature, i.e., σ_s/σ_v is greater at low temperatures. One needs to calibrate the crystal. If a constant voltage supply is used and the current is measured with a sense resistor small compared with the crystal resistance, the output voltage is directly proportional to the conductivity.

Now back to the use of the detector. If the postulate is correct, the compression tube measures about 50% too low at 3×10^{-6} Torr, if one takes the usual correction factor for H_2. It is not yet clear which correction factor one has to use for atomic hydrogen. Therefore, this deviation is not relevant.

TABLE IV.   Summary of the experiment
on ZnO detector.

1. Magnet off

    a. Ram tube p_0 (beam off)   residual gas
                   p_1 (beam on) p_1 is $p_{H_1} + p_{H_2}$

    b. Crystal a_1

2. Magnet on

    a. Ram tube p_2 the same H_2 and more H_1
                   $p_2 - p_1 = \Delta p$ corresponds to the excess H_1

    b. Crystal a_2 $a_2 - a_1 = \Delta a$ this is related to Δp

Transitions. The transition field has been completed, the first oscillator was tested, and a new oscillator was under construction. No transitions have been observed yet.

These are mostly weak field transitions on p. They are also thinking about d. The weak field is sufficient because because one can change the direction of polarization by means of a solenoid.

For protons, they have states 1 and 2 (Fig. A) and want to shift 1 to 3 and then use a high-field ionizer. By a change of frequency and field one can do deuterons.

TABLE V. Data on transitions.

ν[MHz]	ω[sec^{-1}]	H_0[G]	H_1[G]	ΔH[G]	H_1 G	x[cm]
H	17.0	10.7×10^7	12	≈ 1	$\approx \pm 7$	$\gg 0.114$	$\gg 0.5$
D	8.5	5.35×10^7	9.1	1.5	$\approx \pm 7.5$	$\gg 0.32^a$	$\gg 0.23^b$

[a] Adiabatic condition.

[b] Length of region (he has 3.5 cm).
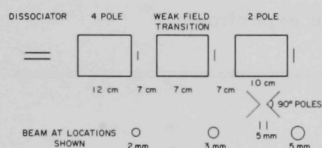
Fig. 81. Arrangement for measurement of transitions.

Fig. 82. Expected or observed results of analysis of transitions using apparatus of Fig. 117. The 4 mm beam is formed by a diaphragm which was adjusted to give the 3.5 mm beam with the 4 pole on.

The arrangement is shown in Fig. 81. The degree of dissociation was measured with iron, platinum, and tungsten units. To get meaningful results (and recombination), the units must be cleaned first. They must be heated to over 200°C. Plates or wires are used with thermoelements on the back. They can be nearby. Expected or observed MoO figures are shown in Fig. 82.

An ionizer using the Penning principle was built but
(Gluch, 1962, unpublished) gave only 0.5 A/Torr in hydrogen residual
gas.

INDEX

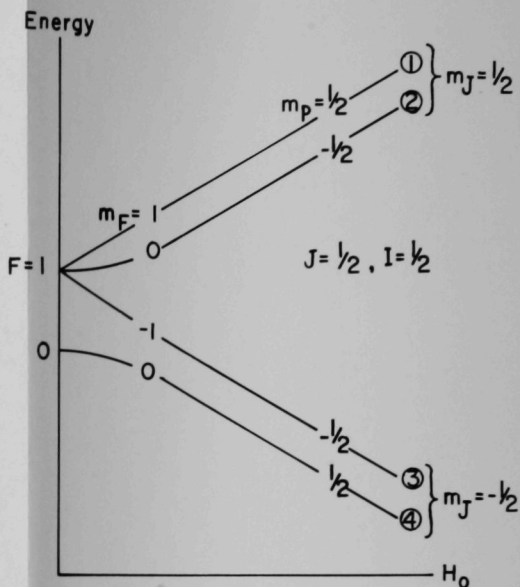Fig. A. Energy level diagram of the hydrogen atom in a magnetic field.
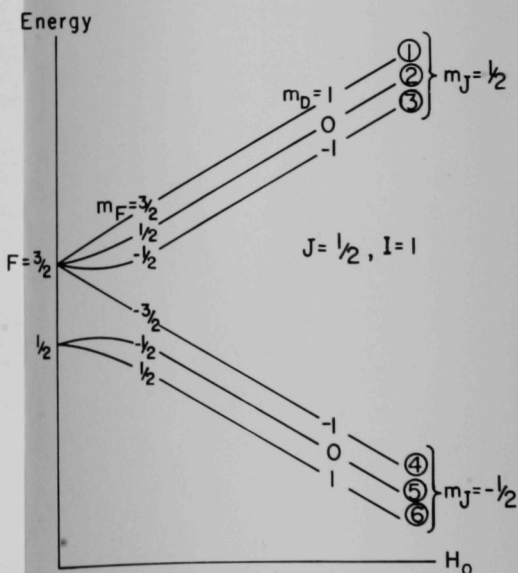

Fig. B. Energy level diagram of the deuterium atom in a magnetic field.

Both figures are for the ground state but the scales are different.